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SPECIES OF RHIZOPUS RESPONSIBLE FOR THE DECAY OF SWEET POTATOES IN THE STORAGE HOUSE AND AT DIFFERENT TEMPERATURES IN INFECTION CHAMBERS [1]

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INTRODUCTION

It has been shown (*6*)[2] that the following species of Rhizopus may decay sweet potatoes: *Rhizopus nigricans*, Ehrenb., *R. reflexus* Bainier, *R. artocarpi* Racib., *R. delemar* (Boid) Wehmer and Hanzawa, *R. oryzae* Went. and Pr. Geerligs., *R. tritici* Saito, *R. nodosus* Namysl., *R. arrhizus* Fischer, and *R. maydis* Bruderl. Infection was accomplished by introducing 24- to 48-hour-old cultures grown on sweet potato decoction into "wells" (*5*) made in the sweet potatoes, the "wells" being sealed over with a cover slip set in vaseline. The potatoes were then placed in moist chambers and incubated at temperatures suitable for infection by the species under investigation. Whether or not the capacity on the part of these species to decay sweet potatoes by the above-mentioned method is an indication of the species involved in the decay of sweet potatoes in the storage house at the Government experimental farm at Arlington, Va., and at different temperatures in infection chambers, will be answered, in part at least, in this paper.

The writers [3] have found, by employing the "well" method of inoculation, that the temperature range at which the parasitic species will infect and decay sweet potatoes is nearly as wide as their temperature growth range in artificial cultures. By this method the species employed have an unusual opportunity to cause infection, even to the exclusion of any other species [4] that might be present in the "wells" or on the surface of the potatoes. It would be difficult for any other species present in the "well" to make any headway against the mass of mycelium of a 48-hour-old culture. What might take place under storage conditions may be a different question. Here the inoculum is limited, the species present are in competition with each other, and all the species may not be present. An effort was made, therefore, to determine whether or not the parasitic species infect sweet potatoes over their entire temperature growth ranges, where infection depends upon wounding and the species present on the potatoes.

Hanzawa (*2*) arranged the species studied by him into three groups according to their temperature relations. There was, as is shown by his

[1] Accepted for publication Aug. 25, 1922.

[2] Reference is made by number (italic) to "Literature cited," p. 456.

[3] This statement is based on unpublished data.

[4] There are nearly always some Rhizopus spores on the surface of sweet potatoes and, since the only precaution observed to eliminate them in these experiments was by washing the potatoes, there probably were occasional spores present.

data, considerable overlapping of the temperature range of one group onto that of another. If spores of all the species were present on the sweet potatoes, one might expect the species found within one of these groups to predominate to a greater or less degree in the amount of infection they provided, within the temperature ranges of the particular group, unless the number of spores of some of the species present that belonged to the other groups greatly exceeded that of the particular group under consideration. Within the limits of their temperature ranges one would expect to find some infection by all the species present. The results of the investigation in this field will be discussed later in detail.

APPARATUS

Much of the investigational work was carried out in a series of insulated infection chambers, the construction and dimensions of which are given in figure 1. Heat is supplied by means of a heating coil composed of

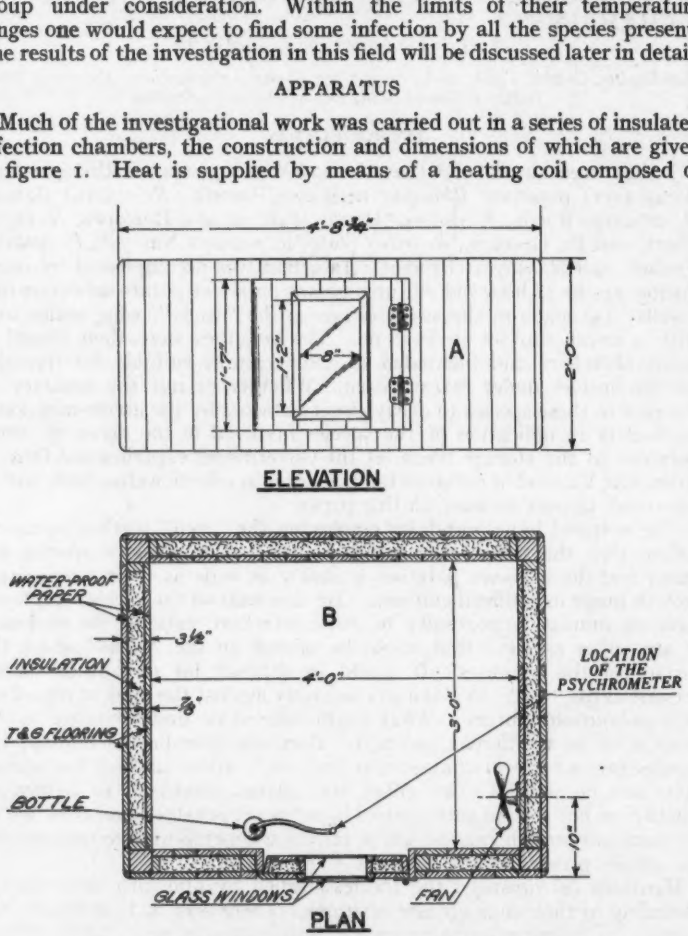

Fig. 1.—Infection chamber. A, front view; B, horizontal cross section.

No. 27 nichrome wire wound around 3/8-inch transite board 2 inches wide and 14 inches long. The floor and end wall immediately adjacent to the heating coils are insulated with transite board. Evaporating pans for the control of the humidity are located one-half inch above the heating coils. Each chamber is provided with standardized dry and wet bulb thermometers, the latter being covered with thin muslin kept wet by a capillary stream of distilled water, the excess of which is drained off by

means of a funnel into a pan located in the door of the chamber. A mercury thermoregulator, which is connected to the heating coils and a 250-ohm relay on a nearby switchboard, is suspended by a rubber band on the back wall. The air within the chamber is kept in motion by means of an 8-inch fan run by a motor located just outside the chamber. The thermoregulator is similar to that designed by Clark (*1*), but differs from it in that there are three arms of mercury instead of one and that one of the electric connections is made directly to one of these arms instead of through a special tube.

The storage house was constructed according to Government plans (*7*). It is provided with two stoves, one at each end, to furnish heat during the curing period, and with steam radiators, one flanking each corner, for the control of the temperature during the winter.

CONTROL OF ATMOSPHERIC ENVIRONMENT IN THE INFECTION CHAMBERS

TEMPERATURE

The thermoregulator used in the chambers controls the temperature within one-half of one degree. The fineness of the control will depend upon the size of the mercury column in the capillary tubing, the amount of mercury used, and its surface area.

The amount of current that passes through the heaters materially affects the control of temperature. Two amperes with a voltage of 110 is all that a 250-ohm relay will handle; in fact, sticking of the relay may be expected at times with this amount. If more current is desired a larger relay should be employed. An ampere and a half is the most that is used in any of the chambers.

To further reduce the danger of sticking, a condenser of 1½ microfarad capacity is employed in connection with each relay. With this type of equipment 20 chambers have been run for 9 months without a single case of sticking.

The capacity of the heaters should be limited to the amount of heat required to heat the chamber to within a few degrees above the desired temperature, otherwise there is a tendency for the temperature to fluctuate or lag.

The amount of current that flows through the thermoregulator should be reduced to a minimum consistent with efficient operation, otherwise the mercury and contact points become insulated and prevent efficient operation.

Direct current is preferable, particularly where mercury thermoregulators are employed. Current with a low number of cycles should not be used when avoidable, since the vibration set up by such a current does not contribute to effective control.

The contact points on the relays should be kept tight, in position, and clean; otherwise they become insulated by the finely divided metal thrown off, especially where a considerable amount of current is used, and thereby reduce the current below that actually required to maintain the desired temperature.

A uniform temperature throughout each chamber was obtained by the use of an 8-inch fan running at about 700 revolutions per minute.

The temperature of the air surrounding a chamber was below that of the chamber, and the desired temperature obtained by heating. The lower temperatures were obtained by placing the chambers in cold storage rooms where the temperature had been reduced by refrigeration.

HUMIDITY

A high relative humidity (about 95 per cent), maintained by means of distilled water in evaporation pans, was used throughout these experiments. The uniformity of the humidity throughout the chambers was maintained by the circulation of the air by means of a fan. In the absence of air circulation there would be, undoubtedly, a higher relative humidity in some parts of the chambers than in others, depending on the vapor pressure in the particular area.

GASES

In order to eliminate any possible effects of gases given off by the sweet potato or other vegetables, provision was made for a constant exchange of air, to be drawn through the chambers slowly by means of a vacuum pump. The amount of air drawn out was roughly determined by drawing it through wash bottles and regulated by stop-cocks.

MATERIALS

The Little Stem Jersey variety of sweet potatoes grown and stored at the Government experimental farm at Arlington, Va., was employed in these experiments. The potatoes were cured for a period of 10 days at temperatures from 25° to 30° C., and held as nearly as possible throughout the season at temperatures between 10° and 14°.

The following species of Rhizopus were employed: *R. nigricans*, *R. tritici*, *R. oryzæ*, *R. reflexus*, and *R. artocarpi*. They were grown on sweet potato agar at a temperature of 20° C.

EXPERIMENTAL DATA

Four types of experiments were used. The methods employed, the purpose of the experiments, and the data obtained will be discussed in connection with each type of experiment.

TYPE ONE

In the first type of experiments the potatoes were merely wounded and placed in the storage house at the Government experimental farm at Arlington, Va., and at different temperatures in the infection chambers. The potatoes were wounded by striking them three or four times on the blunt rim of a wire basket, after which they were placed in wire baskets 12 inches deep and 12 inches in diameter, which were in turn placed in the sweet potato storage house or in the infection chambers.

The purpose of these experiments was to determine what organisms cause decay where infection depends upon the organisms present on the potatoes. The scope of the experiments in this connection was limited to potatoes grown and stored at Washington, D. C. The number of species and the number of spores of each species present on the potatoes might be expected to vary with the locality in which the potatoes were grown, the conditions under which they were stored, and the conditions prevailing in the railway car during transit to the markets and in the markets themselves. The number of spores of a given species also might be expected to vary with the season of the year; in fact, it has been shown that there are fewer spores on the potatoes at digging time and

during the early part of the season than later in the year. There are, however, a sufficient number of Rhizopus spores present during the early part of the season to cause a large percentage of infection when the potatoes are wounded by the method mentioned above.

Fresh wounding contributes materially to infection by Rhizopus.[5] It has been found, as will be shown later in this paper, that fresh wounding is all that is required to permit of infection under the conditions of these experiments.

Table I contains the results of isolations from potatoes that were wounded as mentioned above, but not inoculated. Inspection of the table reveals that two species, *R. nigricans* and *R. tritici*,[6] are probably the species chiefly responsible for the decay of sweet potatoes. The absence of the other species would explain why there was no infection by them, but it is not known whether or not they were present. The presence of *R. tritici* and *R. nigricans* in greater quantity (either as to spores or mycelium) than the other species might explain these results. Later data will indicate to some degree how far this is the case with *R. nigricans*.

TABLE I.—*Isolations*[1] *from uninoculated wounded sweet potatoes held at different temperatures*

Temperatures.	Organisms isolated.	
	Rhizopus tritici.	Rhizopus nigricans.
°C.		
37	60	.....
32	62	3
28.5	8	3
27.5	30	5
26.5	21	19
25	.....	14
23	4	47
20	.....	17
19	.....	6
18	.....	19
15	.....	19
14	.....	78
12	.....	74
11	.....	4
10	.....	20
3.3	.....	4 M.,[2] 2 M. and R. n.

[1] The figures in the columns under the heading "Organisms isolated" represent the number of isolations of the particular organism at the various temperatures. They have no relation to the number of infections, which was always nearly 100 per cent, except between 20° and 30° C., where it was somewhat less. The figures in the succeeding tables under the above heading likewise refer only to the number of isolations.
[2] M.=Mucor. R. n.=Rhizopus nigricans.

Only *R. nigricans* was isolated at temperatures below 20° C. It will be seen, therefore, that *R. nigricans* is the species involved in the decay of sweet potatoes at the usual storage temperatures. The importance of *R. nigricans* on storage will be taken up more fully later.

[5] A paper on wounding as a factor in storage of sweet potatoes is in course of preparation.
[6] Although it is thought by the authors that *R. tritici* is the predominating species at the higher temperatures, it is impossible at present to be certain that *R. nodosus*, *R. oryzae*, and *R. delemar* are not responsible for decay in some instances, and even to the same degree as *R. tritici*. As far as the authors are concerned, there are no characters by which these four species can be definitely separated. *R. tritici*, therefore, will be employed as the name to designate this group of species.

It is interesting to note that *R. tritici* in these experiments did not cause decay of sweet potatoes over its entire temperature range of growth. (Range of growth and infection for *R. tritici* is about 5° to 44–45° C.) Infection by *R. tritici* did not take place by the method employed here, at temperatures at 20° C. and below notwithstanding the fact that it takes place readily where the "well" method of inoculation is used.

The temperature ranges of infection by *R. tritici* and *R. nigricans* overlap between 20° and 30° C. Infection by *R. nigricans* becomes progressively less with the increase in temperature above 20°. *R. tritici* shows a similar decrease in the amount of infection as the temperature passes from 30° to 20°. Infection by the two species becomes nearly equal at 26.5° (Table III).

Results in connection with these and other experiments show that a smaller percentage of the potatoes decay at temperatures between 20° and 30° C. than at higher or lower temperatures. Decay also will start in a large number of cases, then stop. Whether or not these temperatures are more favorable for the potatoes and less favorable for the pathogens, or both, is not clear, except that temperatures near 30° are less favorable for *R. nigricans*.

Table II shows the results of isolations made from wounded but uninoculated potatoes used in experiments in the storage house and in the infection chambers at temperatures at which sweet potatoes are usually stored. The top row of figures represents the average of three experiments, run at different times of the year in the storage house. Most of the isolations proved to be *R. nigricans*. However, in two out of the three experiments, *R. tritici* was isolated in nine instances. Records show that the temperatures were above 20° C. for a few hours during the early part of these experiments. These results indicate that *R. tritici* may be a factor in sweet-potato storage if the temperatures are high enough. *R. nigricans* is, however, the principal cause of decay in the storage house. The four lower rows of figures in Table II represent the results obtained from four experiments run in the infection chambers at temperatures (10° and 14°) corresponding closely to those used in storage. *R. nigricans* was invariably isolated.

TABLE II.—*Isolations from wounded uninoculated sweet potatoes held in the storage house and in the infection chambers at storage temperatures*

Temperatures.	Organisms isolated—Number of cultures isolated.		
	Rhizopus nigricans.	Rhizopus tritici.	Mixed cultures of Rhizopus tritici and Rhizopus nigricans.
°C.			
10–25 [1]	140	9	3
14	78	0	0
12	74	0	0
11	4	0	0
10	3	0	0

[1] The figures 10–25 indicate that the temperature varied between 10 and 25°.

TYPE TWO

In the second type of experiments the sweet potatoes were wounded as above and dipped in a spore suspension made by introducing the spores of an equal number of cultures of *R. tritici* and *R. nigricans*, grown under identical conditions, into 10 gallons of water. From 8 to 10 cultures of each organism were usually employed.

It was discovered in the first type of experiments that *R. tritici* and *R. nigricans* were the species chiefly responsible for the softrot of sweet potatoes at Washington, D. C. *R. nigricans* was responsible for all the decay at temperatures below 20° C., quite to the exclusion of *R. tritici*, notwithstanding the fact that *R. tritici*, as shown by unpublished data, has the capacity of causing decay between 6° and 44°, where the "well" method of inoculation is used. Both *R. tritici* and *R. nigricans* decayed sweet potatoes between the temperatures of 20° and 30° and *R. tritici* above 30°. It is possible that the amount of infection by these species, as well as their temperature ranges, may have been influenced by the number of spores present on the potatoes. The number of spores present of both species, in turn, may have been influenced by local conditions and the conditions under which the potatoes were stored. The storage temperatures were nearly always below 20°, except during the curing period of from 10 days to 2 weeks. Since *R. nigricans* is essentially a low-temperature form, these temperatures are more favorable for its development than for *R. tritici*, which grows better at high temperature. The second series of experiments, therefore, were designed to determine whether or not the range of infection discovered in the first series would be altered in any way, especially the lower limit at which *R. tritici* caused infection, when the sweet potatoes were inoculated with approximately the same number of spores of each species.

Table III shows the results of 920 isolations made during two years in connection with 15 different experiments, most of which were designed to determine the distribution of decay by *R. tritici* and *R. nigricans* at different temperatures. In 12 of these experiments, wounded potatoes were inoculated with a spore suspension of *R. tritici* and *R. nigricans*. In the other 3 experiments the potatoes were wounded but not inoculated, and the data include all the isolations made from potatoes held at 14° C. and 74 out of the 81 isolated from potatoes held at 12°. Some of the experiments in which the isolations were made from potatoes held at low temperatures (7° and below), were designed to determine the lower limit at which these organisms would decay sweet potatoes. In the latter experiments the potatoes were wounded and inoculated as described in the first part of this paragraph. In these experiments the two species are distributed according to temperature, in much the same manner as shown in Table I. The upper and lower limits for infection by *R. tritici* are approximately 44° and 20°, respectively. The highest and lowest temperatures at which *R. nigricans* caused infection were 27° and 3.5°, respectively.

These results tend to indicate that the range of temperatures at which these species will infect sweet potatoes is so wide as to leave little possibility of adjusting temperatures in which to store the potatoes which will be outside the range of infection by these organisms. Although it has been found that these organisms do not cause any appreciable amount of decay at temperatures below 6° C. it was shown by Harter, Weimer, and Adams (*5*), and later verified by the authors, that if potatoes were

held for a few weeks below this temperature they almost invariably decayed with *Mucor racemosus* Fres. There is nearly always 100 per cent infection by *M. racemosus* under cold storage conditions and also in the infection chambers below 6°.

TABLE III.—*Isolations from wounded sweet potatoes inoculated with R. tritici and R. nigricans and held at different temperatures*

Temperatures.	Organisms isolated.					
	Rhizopus tritici.	Rhizopus nigricans.	Mucor.	Botrytis.	Bacteria.	Mixture of organisms.
°C.						
44	3				12	19 P. and[1] bact.
40	10					
39	15					
38	15					
35.4	10					
33.5	39					
32.7	10					
31.4	10					
30.8	33					
30	48					
29.5	25					
28.9	5					
27	35	4				
26	16	14				
23	34	23				2 R. n. and R. t.
20	2	48				1 R. n. and R. t.
19		27				1 R. n. and R. t.
15		21				
14		78				
12		81				
11		46				
10		14				
9		19				
7		10			1	20 M. and R. n.
6		29	24			31 M. and R. n.
5.5			5	22		
3.5		3	15			3 M. and R. n.
2.7			27			
2			10			

[1] P.= Penicillium; bact.= bacteria; R. n.= Rhizopus nigricans; R. t.= Rhizopus tritici; and M=Mucor.

If this method of wounding is employed, whether the potatoes are inoculated or not, the percentage of infection by *R. tritici* and *R. nigricans* is nearly always 100 at temperatures above 30° and below 20° C., respectively, the percentage being lower between these temperatures.

Sweet potatoes are sometimes injured by heat at 40° C. if the humidity is high, and badly injured at 44°, the highest temperature at which *R. tritici* caused infection.

TYPE THREE

The third type of experiments was designed to determine how effectively other species compete with *R. nigricans* in producing infection at the usual storage temperatures. The potatoes were wounded as in previous experiments, some having been previously washed in tap water to reduce if possible the number of spores present on their surfaces and

others were inoculated while in the condition in which they came from the storage house. Washed and unwashed potatoes, wounded in the same manner as those inoculated, were used as controls in all the experiments.

The following species were employed in these experiments: *R. nigricans*, *R. reflexus*, *R. artocarpi*, *R. tritici*, and *R. oryzae*. Washed and unwashed potatoes were inoculated with each of the species alone, except *R. nigricans*. Inoculation in each case was by dipping them into a spore suspension. Washed and unwashed potatoes were inoculated with a mixed spore suspension of *R. reflexus* and *R. nigricans*. Washed potatoes were inoculated with a mixed spore suspension of *R. artocarpi* and *R. nigricans*, and unwashed potatoes with *R. tritici* and *R. nigricans*.

In the preceding experiments *R. nigricans* was shown to be the principal organism causing decay at the usual storage temperatures. This species has also been shown to cause decay of many fruits and vegetables. (*4*) It was found in the second type of experiments that when the sweet potatoes were inoculated with *R. tritici* and *R. nigricans*, *nigricans* caused all the decay below 20° C., notwithstanding the fact that *R. tritici* is not only capable of infecting potatoes at these temperatures, but apparently [7] to the same degree where the "well" method of inoculation is employed.

In view of these facts it was thought desirable to make competitive tests between *R. nigricans* and some of the other species as to their capacity to infect sweet potatoes.

R. tritici was selected, first, because it is the species most commonly isolated from sweet potatoes next to *R. nigricans*, and, second, because with the exception of *R. nigricans* it is the species most commonly received in response to requests to other investigators for cultures of Rhizopus. It has been sent in, on a number of occasions, as *R. nigricans*.

R. oryzae was selected because Hanzawa (*2*) placed it in the high-temperature group (*R. tritici* falling into the intermediate and *R. nigricans* into the low-temperature group) with the idea of studying one organism of each thermal group.

R. reflexus was chosen because it belongs to the same thermal group as *R. nigricans*, its upper temperature limit being slightly higher than that of *R. nigricans* and its lower temperature limit slightly lower. Furthermore, it decays sweet potatoes (where the "well" method is used) fully as rapidly as *R. nigricans*.

R. artocarpi was likewise chosen because it belongs to the same thermal group as *R. nigricans* and is able to decay sweet potatoes over much the same temperature range, where the "well" method of inoculation is used.

The spore suspensions employed in these experiments were made by introducing spores from cultures of the respective species into battery jars containing water. In every case except that of *R. nigricans* the concentration was so great as to render the water almost black.

The reason for using such highly concentrated spore suspensions was to insure ample competition for *R. nigricans*, which, in the first and second series of experiments, successfully excluded *R. tritici* from infecting potatoes at temperatures below 20° C. and which in the course of these experiments proved to be able to compete against odds with the other species.

[7] It is not practical to directly compare the amount of decay caused by one species with that of another because of the indeterminable factors involved, but the indications are that the rate of decay by *R. tritici* is as rapid as that of *R. nigricans* at most temperatures below 20° C.

The spore suspensions of *R. nigricans* used in connection with some of the other species was not so highly concentrated, because it so happened that there was not a sufficient number of cultures of *R. nigricans* available.

Table IV shows the results of competitive tests of infection by *R. tritici* and *R. nigricans*, first when potatoes were washed and inoculated with *R. tritici*, second, when unwashed potatoes were inoculated with *R. tritici*, and third, when unwashed potatoes were inoculated with a spore suspension of *R. tritici* and *R. nigricans*. Controls of both washed and unwashed potatoes were also included.

R. nigricans alone was isolated from the unwashed and control potatoes and greatly predominated when either the washed potatoes were inoculated with *R. tritici* or unwashed potatoes were inoculated with a mixed spore suspension of *R. tritici* and *R. nigricans*. These results indicate that *R. tritici* can not compete with *R. nigricans* and is not much of a factor in the decay of sweet potatoes at these temperatures. The number of spores of *R. nigricans* on the potatoes as they were obtained from the storage house or when the potatoes were washed, was sufficient to cause nearly all the infection, even when the potatoes were inoculated with a highly concentrated spore suspension of *R. tritici*. Washing reduces infection by *R. nigricans* but slightly.

Table V shows that *R. artocarpi* can compete more successfully with *R. nigricans* than *R. tritici*. When *R. artocarpi* is used alone as the inoculum, the percentage of infection is fairly high, especially at 14° C. The washing of the potatoes seems to have no effect. When the inoculations were made with *R. nigricans* and *R. artocarpi* together, no infection by the latter organism took place. *R. nigricans* alone was isolated from the controls.

Although these results show that *R. artocarpi* may cause considerable decay if spore suspensions of high concentration are used, it seems probable that under storage and transit conditions the number of spores of *R. artocarpi* would rarely if ever be sufficient to be a factor in the decay of sweet potatoes, because *R. nigricans* seems to be universally present and would likely grow and produce spores as readily as *R. artocarpi* under most, if not all, conditions.

R. reflexus, as is shown in Table VI, was capable of causing considerable decay when it was used alone as the inoculum.

TABLE IV.—*Organisms isolated from sweet potatoes inoculated with Rhizopus tritici or with a mixed spore suspension of Rhizopus tritici and Rhizopus nigricans, or not inoculated and held as controls*

Temperature.	Inoculated with Rhizopus tritici.					Inoculated with Rhizopus tritici and Rhizopus nigricans (unwashed).		Control.	
	Washed.			Unwashed.				Washed.	Unwashed.
	Rhizopus tritici.	Rhizopus nigricans.	Rhizopus tritici and Rhizopus nigricans mixed.	Rhizopus tritici.	Rhizopus nigricans.	Rhizopus tritici.	Rhizopus nigricans.	Rhizopus nigricans.	Rhizopus nigricans.
°C.									
14.....	2	13	2	0	13	2	6	14	17
12.....	1	25	0	0	13	0	3	12	16

TABLE V.—*Organisms isolated from sweet potatoes inoculated with Rhizopus artocarpi or with a mixed spore suspension of Rhizopus artocarpi and Rhizopus nigricans, or not inoculated and held as controls*

Temperature.	Inoculated with Rhizopus artocarpi.						Inoculated with Rhizopus artocarpi and Rhizopus nigricans (potatoes washed).		Control.	
	Washed before inoculation.			Unwashed.					Washed.	Unwashed.
	Rhizopus artocarpi.	Rhizopus nigricans.	Rhizopus artocarpi and Rhizopus nigricans. (mixed).	Rhizopus artocarpi.	Rhizopus nigricans.	Rhizopus artocarpi and Rhizopus nigricans. mixed.	Rhizopus nigricans.	Rhizopus tritici and Rhizopus nigricans.	Rhizopus nigricans.	Rhizopus nigricans.
°C.										
14.....	11	11	3	16	9	2	13	2 R.t and R.n and 2 R.t.	16	16
19.....	9	16	1	7	26	.....	16	.....	15	17

TABLE VI.—*Organisms isolated from sweet potatoes inoculated with Rhizopus reflexus or with a mixed spore suspension of Rhizopus reflexus and Rhizopus nigricans, or not inoculated and held as controls.*

Temperature.	Inoculated with Rhizopus reflexus.						Inoculated with Rhizopus reflexus and Rhizopus nigricans.		Control.	
	Washed before inoculation.			Unwashed.			Washed.	Unwashed.	Washed.	Unwashed.
	Rhizopus reflexus.	Rhizopus nigricans.	Rhizopus reflexus and Rhizopus nigricans (mixed).	Rhizopus reflexus.	Rhizopus nigricans.	Rhizopus reflexus and Rhizopus nigricans mixed.	Rhizopus nigricans.	Rhizopus nigricans.	Rhizopus nigricans.	Rhizopus nigricans.
°C.										
14.....	12	17	0	10	16	2	22	15	14	17
19.....	17	14	2	16	15	1	8	15	13	30

This species caused no infection, however, when *R. nigricans* was included in the inoculum. Washing the potatoes did not influence the results. These results indicate that *R. reflexus* probably is not normally a factor in the decay of potatoes at storage temperatures.

The results recorded in Table VII show that *R. oryzae* [8] falls into the same group as *R. tritici* with regard to the amount of infection at these temperatures. The only infection that took place was when the potatoes were washed. This fact may have had no relation to washing and may have been accidental, for in the cases of *R. artocarpi* and *R. reflexus*, washing had no effect upon the amount of infection. The effects of

[8] It is assumed for two reasons that *R. oryzae* was the organism that caused the infection, first, because such a highly concentrated spore suspension was used in the inoculation of the potatoes, second, because *R. tritici* or the other species belonging to this group never have been known to cause infection when it was not used in the inoculum, except in the one instance shown in Table V in the case of *R. tritici*.

washing in connection with these experiments and those with *R. tritici* are so small as to fall within the limits of experimental error.

The results recorded in Tables IV, V, VI, and VII show: First, that *R. tritici* and *R. oryzae* can not compete with *R. nigricans* at temperatures of 12° and 14° C. in the infection of sweet potatoes, even where high concentrations of spores of these organisms are used in the absence of *R. nigricans* from the inoculum; second, although *R. artocapi* and *R. reflexus* are more successful than *R. tritici* and *R. oryzae* in competition with *R. nigricans*, they can not compete when the latter is included in the inoculum; third, *R. tritici*, *R. oryzae*, *R. artocarpi*, and *R. reflexus* do not infect sweet potatoes at these temperatures when infection depends upon the organisms present on the potatoes, while *R. nigricans* does.

TABLE VII.—*Organisms isolated from sweet potatoes inoculated with Rhizophus oryzae, or not inoculated and held as controls*

Temperature.	Number of cultures isolated.			Remarks.
	Potatoes inoculated with Rhizopus oryzae.			
	Washed before inoculation.		Unwashed.	
	Rhizopus nigricans.	Rhizopus oryzae and Rhizopus nigricans mixed.	Rhizopus nigricans.	
°C.				
14	14	2	13	Same control as in Table V.
12	13	.....	14	

When comparing the results from experiments with *R. tritici* and *R. oryzae* with those obtained with *R. artocarpi* and *R. reflexus* some reservations must be made because it is not known that the concentration of the spore suspensions are equal or comparable The differences in the amount of infections are so great that they would seem to be due to differences in capacity to infect, rather than to differences in concentration. The concentration was so great in every case that it would seem that a small variation in concentration would alter but little the amount of infection by the particular species used in the inoculum. In fact, very little infection occurred under any circumstances with *R. tritici* and *R. oryzae*. It is reasonable to expect that *R. reflexus* and *R. artocarpi*, especially the former, would cause more infection at these temperatures than *R. tritici* and *R. oryzae*, since the former are low, while the latter are high temperature forms.

It will be seen from Tables V and VI that it may be important in studies of resistance and susceptibility to take into consideration the temperatures at which comparisons are made. For instance, *R. artocarpi* is more successful in competition with *R. nigricans* at 14° than at 12° C., while *R. reflexus* is more successful at 12° than at 14°. These results are consistent with other temperature relations of these organisms, which show that the lower temperature limit for infection with *R. reflexus* is lower than for *R. artocarpi*.

In only one instance has *R. tritici* (Table V) been isolated from sweet potatoes at storage temperatures when the potatoes became infected, in the absence of this organism in the inoculum. It is to be expected that *R. tritici* would be responsible for a small percentage of infections,

since it can infect at these temperatures and probably is nearly always present on the potatoes. (Table I.)

The fact that *R. nigricans* was always obtained from the controls as well as inoculated potatoes in previous experiments when the temperature conditions were right indicates that this species is usually, if not always, present on the potatoes.

TYPE FOUR

In the fourth type of experiments the potatoes were wounded as in the preceding experiments, but inoculated differently. The first inoculation was made with a suspension of spores of *R. tritici*, *R. oryzae*, *R. reflexus*, and *R. artocarpi*, taken from two cultures of each species of the same age and grown under identical conditions, suspended in 3 liters of water; the second inoculation was with a supension of spores of *R. tritici*, *R. oryzae*, *R. reflexus*, *R. artocarpi*, and *R. nigricans*, two cultures of each of the first four species and one of *R. nigricans*. The same amount of water as in the first case was used in making the inoculum.

The object of these experiments was to determine which species would infect sweet potatoes when several species were in competition with each other at storage temperatures. The number of spores of each species present in the inoculum only approximated that of the other species, and in the case of *R. nigricans* was probably much less. Of course, as has been shown in previous experiments, *R. nigricans* is usually, if not always, present, but it is believed that, at least when the potatoes were not inoculated with *R. nigricans*, the number of spores of this species present per unit area was less than that of the other species, because the concentration of the spores in the inoculum of the other species was fairly high.

It did not seem practical at the time to attempt to use exactly equivalent concentrations because of the difficulties involved. The most serious difficulties were, first, to obtain an equal number of spores of each species, second, the number of spores may not be a measure of the germinating and infecting capacity of the spores, which in turn may vary with the species, and, latterly, some variation in the germinating and infecting capacity of the spores of the different species may be expected under different conditions, as, for example, at different temperatures, and yet a comparison between species must be made under identical conditions to be valid. This is shown to be the case by the fact that, although the temperature ranges of *R. reflexus* and *R. artocarpi* run almost parallel, *R. reflexus* is the more successful in competition with *R. nigricans* at 12° C., while at 14° *R. artocarpi* is the more successful (Tables V and VI). It is true that the temperature range of *R. reflexus* is wider than that of *R. artocarpi*, but its maximum is about the same number of degrees above that of *R. artocarpi* as its minimum is below. This difference in temperature ranges is, perhaps, sufficient to account for their difference in infective power. It probably would be difficult to find two fungi of identical temperature ranges. To make a quantitative comparison these factors must be taken into consideration.

It is believed, however, that the results from the methods employed in these experiments will show which species of Rhizopus are important in the decay of sweet potatoes.

Table VIII shows the number of isolations obtained from potatoes inoculated with *R. tritizi*, *R. oryzae*, *R. reflexus*, and *R. artocarpi*, and from potatoes inoculated with the same organisms plus *R. nigricans*, at the temperatures 14° and 18° C. It will be noted that at 18° *R. artocarpi*

was isolated from 17 potatoes as compared with *R. nigricans* from 4, when *R. nigricans* was not included in the inoculum. On the other hand, *R. artocarpi* was obtained from only 6 potatoes as compared with *R. nigricans* from 11 (and in 3 of these cases the isolations were a mixture of *R. artocarpi* and *R. nigricans*) when *R. nigricans* formed a part of the inoculum. At 14° quite a different relationship was found. When *R. nigricans* was excluded from the inoculum, *R. artocarpi* was isolated from 6 potatoes (4 of these isolations were a mixture of *R. artocarpi* and *R. nigricans*), *R. nigricans* from 29 and *R. reflexus* from 3. When *R. nigricans* was included in the inoculum, *R. artocarpi* was isolated once, a mixture of *R. artocarpi* and *R. nigricans* twice, and *R. nigricans* 33 times. These results show, first, that the percentage of infection by *R. artocarpi* was higher when *R. nigricans* was excluded from the inoculum, although at 14° the difference was small; second, that 18° was more favorable for infection by *R. artocarpi* than 14°. This was especially evident when *R. nigricans* was excluded, in which case the infection by *R. artocarpi* greatly exceeded that of *R. nigricans;* third, that a temperature of 14° was more favorable for *R. reflexus* than one of 18°; fourth, that *R. artocarpi* showed a slightly higher percentage of infection at 14° than *R. reflexus* (these results correspond to those recorded in Tables V and VI); fifth, that *R. tritici* and *R. oryzae* at these temperatures infect less readily than either *R. artocarpi* or *R. reflexus;* and sixth, that *R. nigricans* infects more readily than any of the other species. This is shown, even when infection by *R. nigricans* is compared with that of *R. artocarpi* at 18°, because although *R. artocarpi* caused the greater part of the decay when *R. nigricans* was excluded from the inoculum, the reverse was true when *R. nigricans* was included. This was true notwithstanding the fact that two cultures of *R. artocarpi* were used as compared with one of *R. nigricans.* Even assuming that spores of *R. nigricans* on the potatoes were equal in number to the *R. artocarpi* spores in one culture and the number of spores in the cultures of the two were equal, the margin is much in favor of *R. nigricans.* It is believed that there is a greater number of spores in a culture of *R. artocarpi* than in a culture of *R. nigricans.*

The percentage of infection by *R. artocarpi* and *R. reflexus* as compared with *R. nigricans* is not as high in these experiments as is shown in Tables V and VI at 14° C., but the concentration of the spores in the inoculum was not as high in the latter as in the former case.

TABLE VIII.—*Organisms isolated from wounded sweet potatoes inoculated with a mixed suspension of spores of a number of species of Rhizopus*

Organisms employed.	Temperature.	Number of isolations.	Organisms isolated.
	°C.		
Rhizopus tritici, oryzae, reflexus and artocarpi.....	18	21	17 R. artocarpi. 4 R. nigricans.
	14	38	2 R. artocarpi. 4 R. artocarpi and nigricans, mixed. 29 R. nigricans. 3 R. reflexus.
Rhizopus tritici, oryzae, reflexus, artocarpi and nigricans.....	18	17	3 R. artocarpi. 3 R. artocarpi and nigricans, mixed. 11 R. nigricans.
	14	36	1 R. artocarpi. 2 R. artocarpi and nigricans, mixed. 33 R. nigricans.

DISCUSSION OF RESULTS

R. tritici and *R. nigricans* are the two species chiefly responsible for the decay of sweet potatoes, known as softrot. The former is responsible for decay at the higher and the latter at the lower temperature, while the two overlap between 20° and 30° C. Although other species are capable of causing softrot, they do not seem to do so under the storage conditions at Washington, D. C., and in the infection chambers at the different temperatures. *R. tritici*, *R. oryzae*, *R. reflexus*, and *R. artocarpi* cannot compete successfully with *R. nigricans* at temperatures of 12° and 14° when sweet potatoes are inoculated with any one of these organisms along with *R. nigricans*. Even though high concentrations of spores of *R. tritici*, *R. oryzae*, *R. reflexus*, and *R. artocarpi* are used alone, *R. nigricans* nearly always causes more decay than any of them, and *R. tritici* and *R. oryzae* cause very little under such conditions.

When a mixed spore suspension of *R. tritici*, *R. oryzae*, *R. reflexus*, and *R. artocarpi* is used in inoculating the potatoes held at temperatures of 14° and 18° C., *R. artocarpi*, *R. reflexus*, and *R. nigricans*, with *R. nigricans* greatly predominating, were isolated at 14°, and *R. artocarpi* and *R. nigricans* at 18°, *R. artocarpi* greatly predominating. When *R. nigricans* was added to the inoculum just mentioned, *R. nigricans* and *R. artocarpi* were the only species isolated, with the former greatly predominating.

These results show that *R. nigricans*, except in the case of *R. artocarpi* at 18° C. (when *R. nigricans* was not included in the inoculum), was the chief agent of decay, even in the presence of the highly concentrated spore suspension of the other species used in these experiments.

Why *R. nigricans* should cause so much decay when such high concentrations of spores of the other species were employed, especially in the cases of *R. reflexus* and *R. artocarpi*, cannot be explained now. This seems rather strange when it is considered that *R. reflexus*, in particular, seems to decay sweet potatoes fully as rapidly as *R. nigricans* when the "well" method of inoculating is employed at the same temperatures. The two cases are hardly comparable, however, since in the present experiments we are dealing with the percentage of infection, while in the case cited we have to do with the rapidity of decay after infection has occurred. When the "well" method is used there is nearly always 100 per cent infection, irrespective of the species employed. This method is not at all comparable, however, to the one employed in these experiments.

When these results are compared with those obtained by Harter, Weimer, and Lauritzen (*6*), who showed that several species of Rhizopus have the capacity to decay sweet potatoes, one should take into consideration the methods employed in the two cases. In the former case the particular species involved in infection was not only present as a concentrated mass of active mycelium, but had the additional advantage of having access to the available food still remaining in the decoction. The species concerned also had access to the food rendered available soon after inoculation by the action of the pectinase, present in the decoction, upon the middle lamellae (*3*). In the latter case, infection depended either upon the spores present on the potatoes as they were removed from storage, or upon the spores introduced as a suspension in water. Where the potatoes were not inoculated, the species present may have been limited to those (*R. tritici* and *R. nigricans*) isolated in the first type of experiments. If other species were present, they were

unsuccessful in competition with these two species. When the potatoes were inoculated as above, the competition between the species present, whether introduced or occurring normally, was more nearly equal than it was between the species present on the potatoes as they came from storage and the inoculum used in connection with the "well" method.

It should be realized from a comparison of the results obtained by the two methods, that because a fungus produces a disease under one set of experimental conditions, it does not necessarily do so under another. The factors involved in determining infection under experimental conditions may vary greatly from those under normal conditions, depending upon, first, whether or not the experiments are designed to approximate normal conditions, and, second, whether or not the circumstances and our knowledge enable us to recognize and control the factors involved.

There seems to be some unknown factor or factors, either as a part of the capacity to decay, or associated with it, on the part of *R. nigricans* that enables it under normal conditions or the conditions of these experiments to infect sweet potatoes to the exclusion of the other species.

SUMMARY

(1) *Rhizopus nigricans* and *R. tritici* are the species primarily responsible for the decay of sweet potatoes known as softrot, *R. nigricans* at temperatures between 6° and 20° C., and *R. tritici* at 30° and above, the two overlapping between 20° and 30°.

(2) The temperature range of infection by *R. tritici*, *R. nigricans*, and *Mucor* is so wide as to exclude the possibility of storing sweet potatoes beyond the limits of this range.

(3) *R. tritici*, *R. oryzae*, *R. reflexus*, and *R. artocarpi* can not compete successfully with *R. nigricans* at the temperatures of 12°, 14°, and 18° C.

LITERATURE CITED

(1) CLARK, W. Mansfield.
1920. THE DETERMINATION OF HYDROGEN IONS . . . 317 p., 38 fig. Baltimore. Bibliography, p. 239–302.

(2) HANZAWA, Jun.
1914–15. STUDIEN ÜBER EINIGE RHIZOPUS-ARTEN. *In* Mycol. Centbl., Bd. 5, p 230–246, 257–281, 12 fig.

(3) HARTER, L. L., and WEIMER, J. L.
1921. A COMPARISON OF THE PECTINASE PRODUCED BY DIFFERENT SPECIES OF RHIZOPUS. *In* Jour. Agr. Research, v. 22, p. 371–377, 2 fig.

(4) ——— ———.
1922. DECAY OF VARIOUS VEGETABLES AND FRUITS BY DIFFERENT SPECIES OF RHIZOPUS. *In* Phytopathology, v. 12, p. 205–212. Literature cited, p. 212.

(5) ——— ——— and ADAMS, J. M. R.
1918. SWEET-POTATO STORAGE-ROTS. *In* Jour. Agr. Research, v. 15, p. 337–368, pl. 21–27. Literature cited, p. 366–368.

(6) ——— ——— and LAURITZEN, J. I.
1921. THE DECAY OF SWEET POTATOES (IPOMOEA BATATAS) PRODUCED BY DIFFERENT SPECIES OF RHIZOPUS. *In* Phytopathology, v. 11, p. 279–284. Literature cited, p. 284.

(7) THOMPSON, H. C.
1918. SWEET-POTATO STORAGE. U. S. Dept. Agr. Farmers' Bul. 970, 27 p., 15 fig.

THE INHERITANCE OF GROWTH HABIT AND RESISTANCE TO STEM RUST IN A CROSS BETWEEN TWO VARIETIES OF COMMON WHEAT [1]

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INTRODUCTION

There are three general methods by which the tremendous destruction of wheat by black stem rust may be reduced. These are the eradication of the common barberry (*13*),[3] the growing of rust-resistant varieties (*1*, *10*), and the use of improved methods of field culture (*14*). The losses have been especially severe in the hard red spring wheat area. No hard red spring wheat of high quality and yield, which is generally resistant to stem rust in the hard spring wheat belt, is now grown on a large acreage. Kota, apparently, is highly resistant to stem rust in those districts in which it has been grown, but on account of weak straw it is likely to lodge in the more humid sections. Therefore, the importance of developing other rust-resistant hard red spring wheats is quite apparent.

The production of varieties of wheat resistant to stem rust is a complex problem. Until recently it was supposed that only one form of stem rust caused the epidemics on wheat, although some of the early workers believed that the parasitic capabilities of the rust were easily modified (*2*). However, Stakman and Piemeisel (*17*), followed by others (*8*, *9*, *15*) have shown that *Puccinia graminis tritici* Erikss. and Henn. in reality consists of many biologic forms which differ in their pathogenicity for certain varieties of wheat.

This discovery explains why the same variety of wheat may be resistant when grown in one locality and susceptible when grown in another, or why a variety may be resistant in the same locality in one year and susceptible in the next. It is obvious that if a wheat is to be resistant in the field it must be resistant to all of the biologic forms present in the locality in which it is to be grown.

Both Kanred and Marquis are good milling and high yielding wheats. Kanred, however, is practically immune from several biologic forms of stem rust to which Marquis is susceptible. The purpose of this paper is to present data regarding the mode of inheritance of growth habit (winter versus spring habit) and resistance to stem rust in a cross between Kanred and Marquis wheats.

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[1] Accepted for publication Aug. 21, 1922.

[2] This work on the development of rust-resistant varieties of wheat was under the direction of Dr. H. K. Hayes and Dr. E. C. Stakman. The cross was made in 1918 by Carl Kurtzweil and others. The seed of the first generation was furnished by Doctor Hayes. The biologic forms of rust were supplied by Doctor Stakman and Mr. M. N. Levine.

[3] Reference is made by number (italic) to "Literature cited," pp. 468-469.

Hayes, Parker, and Kurtzweil (7) recently studied the inheritance of resistance and susceptibility, to what apparently was a single biologic form, in crosses between common and durum wheats and common wheat and emmer. They showed that the inheritance of resistance and susceptibility to stem rust was not the same in different crosses. In the durum-common cross, susceptibility appeared to be dominant while in the emmer-common cross the F_1 was resistant, but not as resistant as the emmer parent. There was some linkage in transmission between the emmer and durum types and resistance to stem rust. Resistant emmer and durum types were very common, while it was quite difficult to obtain resistant common wheats.

Puttick (*11*) reported the results of a study on the reaction of the F_2 plants of a cross between two varieties of wheat which react reciprocally to two biologic forms of stem rust. Many gradations in reaction to both forms of rust appeared, varying from complete susceptibility to complete immunity.

Extensive rust surveys have been made during the last few years. The prevalence, distribution, and virulence of the various biologic forms of *Puccinia graminis tritici* are now being ascertained and, for all practical purposes, the parasitic effect on the hosts seems to be constant (*16*). The plant breeder now has a definite basic foundation for the development of varieties resistant to stem rust.

Twenty-one biologic forms [4] of rust have been found in the upper half of the Mississippi Valley. As the winter wheat, Kanred, is resistant to 2 of these forms and immune from 11, the value of this variety in breeding a rust-resistant spring wheat is apparent. If there could be isolated from the progeny of a Kanred-Marquis cross, a spring wheat which would be resistant to some or all of the forms to which the winter parent is resistant, one step would be accomplished of the many needed to produce a generally resistant variety.

Kanred is a true winter wheat which, when sown in the spring, at University Farm, St. Paul, Minn., produces only an occasional head late in the season and does not set seed. Marquis is a true spring wheat, which, when sown in the fall, seldom, if ever, lives through the winter. Growth habit, as used in this paper, is meant to indicate that general difference which exists between true spring and true winter varieties in their ability to produce heads normally when sown in the spring of the year (Pl. 1, A).

Apparently few investigations have been made on the inheritance of growth habit. Innumerable observations have been reported in literature on the differences in heading period and maturity between varieties in both spring and winter groups. These differences, while they may be of the same general nature as winter habit, are comparatively very minute, but they are constant, as was shown by Fruwirth (*3*) in 1918.

A single head of wheat was selected and divided into two parts. One-half of this seed and its progeny was constantly sown in the fall and the other half in the spring. This process was continued for 8 years. The two lots of seed were then sown together in both the fall and spring and the growth habits compared. The period of blossoming and ripening was the same for all plots, showing that selection within a pure line was of no value.

[4] Unpublished data furnished by E. C. Stakman and M. N. Levine.

The nature of the processes involved in bringing about the heading period has been a matter of speculation for some time. The climatic units which control these processes and permit winter grains to produce seed are finely interwoven. Although temperature and moisture are very important factors in the growth and maturing of plants, it is quite evident from the plant life about us that the time of flowering and fruiting of most plants is definitely connected in some way with the advance of the season. Garner and Allard (*6*) have clearly demonstrated this third factor to be the change in length of day and night. They found that certain plants which ordinarily require a short day for flowering and fruiting could be induced to flower and fruit in the middle of the summer by shortening the length of day to that which was normal for the regular flowering season. This was done by placing the plants in a dark-house for a certain number of hours each day.

In contrast to this group of plants which require a short day for flowering and fruiting, is that group of plants which require a long day of light. These plants flower regularly in the late spring or early summer. Garner and Allard place our small grains in this group.

As regards the inheritance of the growth-habit character, the results reported by previous workers do not appear at first to be in full agreement. Spillman (*12*) reported in 1909, that the winter character was dominant over the spring character in a cross between a winter common wheat and a spring club wheat. Fruwirth (*4, p. 176*) in 1910, cites Tschermak as having reported that the winter type was dominant over the spring type. When sown in the fall, the first generation of hybrids wintered over somewhat better than the true winter forms; but when sown in the spring, they remained dormant through nearly the whole summer. Single shoots appeared and began to blossom, but they produced no seed.

Gaines (*5, p. 42–45*) in 1917, reported that he obtained a segregation of spring and winter types from a cross between 2 spring varieties of barley, Rice and Beardless. The F_1 when sown in the spring, headed normally. In the F_2 there was a ratio of 3 winter plants to 13 spring plants. The plants in the third generation bred fairly close to expected ratios. He found that seasonal variations influenced the heading periods and consequently the ratios. The segregation in the F_2, however, indicates a dominance of the spring type over the winter type.

A complete and detailed study of the genetic nature of growth habit in wheat varieties has been made recently by Vavilov and Kouznetzov (*18*). They crossed a common winter wheat with a club spring wheat and found a clear dominance of the spring character over the winter character. There was a complicated segregation in the F_2, and some of the segregates (including many intermediates) were homozygous in the F_3. Of the 552 F_2 plants, 500 were early or late spring plants and 52 were typical winter plants. The results obtained by the writer on the inheritance of spring and winter habit are quite in accord with those of Vavilov and Kouznetzov.

MATERIALS AND EXPERIMENTAL METHODS

Marquis, a hard red spring common wheat of high quality, was crossed with Kanred in the summer of 1918. The latter, which is immune from several different biologic forms of stem rust, is a high yielding selection from Crimean hard red winter wheat.

The crossed seed was sown in the fall of the same year and produced 80 plants, 2 of which were winterkilled and 5 of which were not crosses. The remaining plants were harvested individually and the seed sown in the spring of 1920.

In the second generation a population of approximately 5,000 plants was grown. In order to facilitate observations the seeds were sown at intervals of 3 inches, in rows 1 foot apart. The date of emergence of the first head on each plant was noted. The hybrids formed a continuous series for date of head emergence, beginning with those which came out at the same time as the spring parent, to those which did not emerge at all. In this way they resembled the winter parent. (Pl. 1, B.)

The time of heading was divided into weekly periods. One week from the day on which the first plant headed, tags were placed on plants on which one or more heads had emerged. These comprised the first class. All of the Marquis control plants headed during the same period as did those plants included in the first class. One week later, tags were attached to all plants which had headed since those of class 1. These constituted the second class. This process was continued for 8 weeks, after which period no more plants headed. The plants which did not head were classed as true winter types. The winter parent controls failed to head, thereby falling into the same class as the winter hybrids.

From the first 7 heading classes in the F_2, 65 families were grown in the F_3. The plants from the seventh class produced only a few seeds, while those of the eighth class headed so late that no seed was produced at all. In sowing, the seed was again spaced as in the second generation so that a study could be made of the individual plants.

Several of the families were uniform for heading period in the F_3. In these cases the entire plot was given a general heading date, as in a varietal test. Others of the families were heterozygous for date of head emergence. In those plots a final count was made at harvest time of the number of plants which failed to head and the number which produced heads.

The rust studies were made on plants growing in the field under an artificial epidemic produced with several different biologic forms of stem rust and also on inoculated seedlings in the greenhouse.

In the second generation all the plants were grown in the field under an artificial epidemic produced by spraying the plants with a suspension of urediniospores of several different biologic forms. Both parents were susceptible to some of the rust forms which were used. All of the hybrid material was as susceptible as either parent in this epidemic and therefore a detailed genetic study of the inheritance of rust resistance under field conditions could not be made. Studies on the inheritance of resistance and susceptibility were made in the greenhouse by inoculating the F_3 seedlings with cultures of urediniospores of known biologic forms.

The seedlings in the greenhouse were grown in 4-inch pots and inoculated when they were 1½ to 2 inches tall. After inoculation they were placed in a glass-topped chamber and incubated 48 hours. The notes on infection were taken 12 to 14 days after the date of inoculation. Some of the plants were completely susceptible and the others were immune since there were no intermediate types of infection. The uredinia were large, coalescing, and normal in every respect on the seedlings both of Marquis and of susceptible hybrids, while the seedlings of Kanred and

of the resistant hybrids were immune. There were, therefore, only two classes, i. e., immune and susceptible.

An intensive study was made by testing a large number of F_3 plants with a single known biologic form to which the Marquis parent is susceptible and the Kanred parent is resistant. Two questions then naturally arise: How is the reaction tendency of the host to all of these biologic forms inherited? Is the reaction due to the presence of a single genetic factor, or, if several factors are concerned, are they linked in the process of segregation? An attempt was made to solve these questions by inoculating various F_3 selections, which were homozygous in their reaction to the first form studied, with 12 other biologic forms of stem rust.

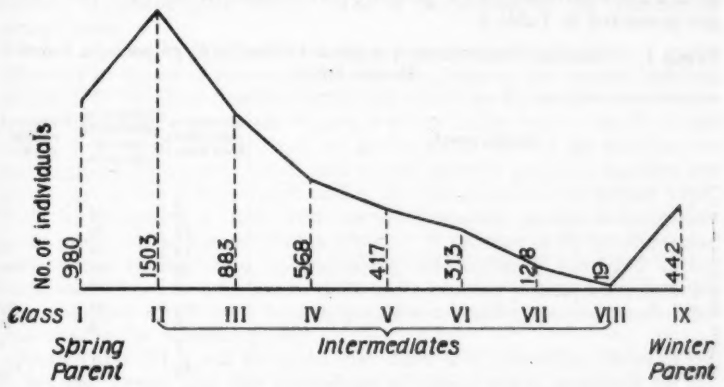


Fig. 1.—Diagram showing the segregation for time of heading in the spring-sown F_2 of a Marquis × Kanred hybrid.

EXPERIMENTAL RESULTS

THE MODE OF INHERITANCE OF GROWTH HABIT

The first generation material was sown in the fall. Because of the mildness of the season, only 2 out of 75 plants were killed during the winter. Had the winter been severe, it is possible that a higher percentage of the first generation plants would have been killed. No F_1 plants were grown from spring-sown seed.

All of the seed from the F_1 was sown in the spring of the following year, producing an F_2 population of 5,250 plants. Of this number 4,808 plants headed during the summer and 442 plants did not. Of the former, 980 plants headed at the same time as did the spring parent. In the second weekly period 1,502 plants headed, which is the greatest number to fall into any one heading period. From the second period on to the eighth, there was a gradual decrease in the number of plants heading. In the eighth period there were but 19 plants. The total number for each class is shown in figure 1.

It is very evident from the chart that the segregation of the plants for growth habit characters in the F_2 is of a complex nature. All of the plants in the first 5 classes matured like any ordinary spring wheat variety. It would be quite fair, then, to assume that in general, the plants in these

first 5 classes could represent reasonably well the true spring type. If such were the case, there would be 4,350 plants of the spring type and 900 of the winter, a ratio of approximately 5 spring plants to 1 winter plant. If it were assumed that all plants which headed during the summer were of spring type, there would be a ratio of approximately 11 spring to 1 winter. In either case there is a partial dominance of the spring over the winter habit.

A study was made to ascertain whether any correlation existed between the inheritance of growth habit and the presence of awns. A total of 432 plants were tabulated according to their growth habit in relation to this character. The awn characters were recorded from the F_2 individual plants and controlled by the progeny performance in the F_3. The results are presented in Table I.

TABLE I.—*The relation between awns and growth habit in the F_2 progeny of a Kanred × Marquis hybrid*

Heading period.	Number of plants with long awns.	Number of plants with intermediate awns.	Number of awnless plants.
1	18	25	14
2	17	29	11
3	14	21	16
4	21	21	24
5	23	26	16
6	29	41	38
7	6	9	11
8	1	.....	1
Total	129	172	131

The results presented in Table I show that there is a lack of correlation in the inheritance of awns and growth habit characters. While the numbers are not very great for each separate heading period, there is a total of 129 bearded plants compared to 131 beardless plants for the first 8 periods.

The segregation of plants for growth habit in the F_3 families was in accord with the segregation obtained in the F_2. The growth habit of the plants belonging to the various F_2 groups is shown in Table II.

TABLE II.—*The growth habit in F_3 of plants belonging to separate F_2 heading groups in a Marquis-Kanred hybrid*

Heading period.	Number of families.			
	Grown.	Homozygous for spring habit.	Heterozygous for growth habit.	Homozygous for winter habit.
1	10	10	0	0
2	10	6	4	0
3	10	7	3	0
4	10	5	5	0
5	10	2	8	0
6	9	0	9	0
7	6	0	4	2

The plants selected from the first heading period in the second generation were homozygous for the spring habit of growth in the third generation. Beginning with the plants in the second heading period, there was a gradual decrease in the number of families which were homozygous for the spring character and a corresponding increase in the number of families heterozygous for the same character as the seventh heading period was approached. There was also a gradual change in the ratios of spring to winter types progressing from the first to the seventh heading period. In the seventh period, 2 families were homozygous for winter character. If the plants in the eighth class had produced seed in the second generation, there undoubtedly would have been a still larger number of homozygous winter types in proportion to the number of spring types.

One can readily see from the data presented that there is a great difference in degree of heterozygosity of the plants in the various heading periods. In the first heading period all 10 of the F_3 families are homozygous for spring type; in the second, 6 of 10; in the third, 7 of 10; in the fourth, 5 of 10; in the fifth, 2 of 10; in the sixth, all 9 of the families are heterozygous for growth habit, and in the seventh period 4 families are heterozygous for growth habit and 2 are homozygous for winter type. With the exception of those from the sixth heading period, homozygous forms were obtained in all classes grown. A number of F_3 families were homozygous spring types comparable to our ordinary hard red spring wheat varieties. In addition to these early-heading plants, a few families were obtained which were homozygous for a heading period much later than that of the Marquis parent.

From Table III it will be noted that there is a correlation between the F_2 heading period and the percentage of spring types produced by the various F_3 families.

TABLE III.—*Showing the growth habit of the F_3 from F_2 plants heterozygous for growth habit*

Heading period.	Number of types.		Spring types.
	Spring.	Winter.	
			Per cent.
1	All.	None.	100
2	154	13	92.2
3	121	14	89.6
4	158	39	80.2
5	236	46	83.7
6	187	69	73
7	12	6	66.7

With the exception of the very slight increase in the fifth heading period, there is a very regular decrease in the percentage of spring types to winter types as one proceeds from the first to the seventh heading period. Here also there undoubtedly would have been a more complete reversal of the ratios of spring types to winter types in plants of the eighth and ninth heading periods, had it been possible to grow these plants in the third generation.

THE MODE OF INHERITANCE OF RUST RESISTANCE

The F_1 plants grown in the field during the summer of 1919 were not infected, since no rust developed in the field where they were grown. Consequently no determinations of resistance or susceptibility could be made under field conditions.

The F_2 plants were extremely susceptible when grown in the field under an epidemic produced artificially by inoculation with several biologic forms. The Marquis control plants, which are completely susceptible to all of the forms used in producing the epidemic, had an average rust infection of 87.7 per cent. The hybrids growing under the same conditions had an average rust infection of 80 per cent. This high susceptibility of the hybrids growing in the field was to be expected, because both the Marquis parent and the Kanred parent are susceptible to some of the forms used in producing this epidemic. These results very clearly demonstrate how a general field epidemic may fail to differentiate the segregation for resistance and susceptibility in the progeny from a given cross. The most accurate and reliable method of determining the resistance and susceptibility of hybrid progeny to any given number of biologic forms is to grow the plants under controlled conditions and to inoculate them with single known biologic forms.

The plants of 10 families from each of the first six classes, and 5 families from the seventh class, for growth habit (fig. 1), were tested for their reaction to Biologic Form I. This form is one which has been carried in pure culture since 1916 and has remained constant in its reaction on various host plants throughout this period. Of the 65 families tested, 23 were pure for resistance to this form of rust, 10 were susceptible, and 32 were heterozygous. The ratios are not very significant when taken from such a small number of families. There is a numerical ratio of 23 resistant families, 32 heterozygous, and 10 susceptible. The ratio of homozygous to heterozygous families is a very close approximation to the expected 1:1 ratio. The inoculation results are given in Table IV.

TABLE IV.—*The reaction of Marquis and Kanred, and various families of the F_2 from a cross between Kanred and Marquis, to Biologic Form I of stem rust* [1]

Class.	Homozygous for resistance.		Heterozygous for resistance.			Homozygous for susceptibility.	
	Number of families.	Number of individuals.	Number of families.	Number of individuals resistant.	Number of individuals susceptible.	Number of families.	Number of individuals.
1	3	102	4	96	26	3	82
2	3	75	7	184	54	0	0
3	3	108	4	102	35	3	88
4	1	21	8	239	59	1	26
5	4	111	4	89	28	2	73
6	6	140	3	65	18	1	24
7	3	50	2	23	2	0	0
Total	23	607	32	798	222	10	293
Marquis	.....	0	.....	0	0	.....	83
Kanred	.....	83	.....	0	0	0	0

[1] A total of 2,086 individual plants were inoculated. The resistant hybrid plants were just as free from lesions as the resistant Kanred parent. The susceptible hybrid plants were completely susceptible, producing large, vigorous, and confluent uredinia. This type of infection was like that obtained on the Marquis parent (Pl. 2).

There were 1,020 individuals in the 32 families which were heterozygous in their reaction to Biologic Form I. Of this number, 798 were immune, while 222 plants were clearly susceptible, an approximate ratio of 3 resistant plants to 1 susceptible. In some cases there were a few plants which failed to become infected in families which, judging from the majority of the plants inoculated, should have reacted as homozygous for susceptibility. Upon reinoculation it was found that the plants really were susceptible and had merely escaped infection. In the case of the heterozygous families it is not surprising, therefore, that the number of resistant plants is a little larger than expected. Apparently, there should have been a simple ratio of 3 resistant plants to 1 susceptible. There is a deviation from the expected of 33 ± 9.33.

From these data it is very evident that the segregation for resistance and susceptibility to this one biologic form of stem rust is very simple. Many desirable types were obtained in the F_3 which are homozygous for spring habit or growth and are immune from Biologic Form I.

Several F_3 selections, homozygous in their reaction to Form I, were inoculated with 12 other biologic forms. The results obtained were very striking and consistent, and are presented in Table V.

TABLE V.—*The reaction of Marquis, Kanred, and F_3 families of the cross between Kanred and Marquis, to 13 biologic forms of stem rust*

Biologic form.	Variety or hybrid family number.																
	Marquis.	Kanred.	29	30	31	41	42	43	47	48	54	55	60	79	80	205	181
I	[1] S	I	.....	.....	I	I	.....	.....	.....	I	I	I	I	I	I	I	S
III	S	S	.....	.....	.....	S	S	S	S	S	.....	.....	S	S	S	S	S
IX	S	I	I	I	.....	I	.....	.....	.....	.....	.....	I	.....	.....	I	I	S
XIV	R	I	I	.....	.....	I	I	I	I	I	.....	.....	.....	.....	I	.....	.....
XVII	S	I	I	.....	I	I	.....	I	.....	.....	.....	.....	I	.....	.....	I	S
XVIII	S	S	S	.....	S	S	.....	.....	.....	S	.....	.....	S	S	S	S	S
XIX	R	I	.....	.....	I	I	.....	.....	.....	I	.....	.....	I	I	I	I	.....
XXI	S	I	.....	.....	I	I	I	.....	I	I	.....	.....	I	I	I	I	S
XXIX	S	I	I	I	I	I	.....	I	.....	I	I	I	I	I	I	.....	.....
XXXII	S	S	.....	.....	.....	S	.....	.....	S	S	S	S	S	.....	.....	.....	.....
XXXIV	S	S	.....	S	.....	S	.....	.....	S	.....	S	S	S	S	S	.....	.....
XXXVI	S	S	.....	S	S	S	S	.....	S	.....	.....	.....	.....	.....	.....	.....	.....
XXXVII	S	I	I	.....	I	I	.....	.....	I	I	I	I	I	.....	I	.....	.....

[1] S=Completely susceptible; I=immune; R=resistant, a type of infection intermediate between that of S and I.

It will be noticed in Table V that as far as the reaction of the two parents is concerned, the 13 biologic forms of rust may be placed into 2 groups. The first group is typified by Form I, to which Marquis is susceptible and from which Kanred is immune.

The second group is represented by Form III, to which both Marquis and Kanred are susceptible. Here it will be seen that all of the progeny are as susceptible as either parent and identical in their reaction in this respect.

The hybrid families may also be placed in two groups; (*a*) those whose rust reactions are similar to the Marquis parent, and (*b*) those that are similar to the Kanred parent. Family 41, for example, is identical with Kanred in its rust reaction to all of the forms used, and family 181 is identical with Marquis in its rust reaction to all forms used.

These results very definitely demonstrate that resistance and susceptibility to several biologic forms of stem rust may be carried either in a single genetic factor or in different factors linked in the process of segregation.

With this fact established, it has been possible to inoculate the progeny from this cross with a single biologic form of rust from which the Kanred parent is immune. By their reaction to this one form it is clear that without inoculating they will react similarly to the other biologic forms from which Kanred is immune. In this manner, numerous F_3 selections have been obtained which are pure spring types immune from all of the known biologic forms of stem rust from which the Kanred parent is immune.

DISCUSSION OF RESULTS

The results show very clearly the complicated nature of the genetic difference between a spring and a winter variety of wheat. The results could not be explained very well on a simple monohybrid or dihybrid basis. The segregation indicates very minute differences for this character between the individual plants. While the time of heading was divided only into weekly periods, it was very evident during the progress of the experiments that the differences between the individual plants could be determined within a few days. For practical purposes and convenience in gathering the data, however, it was decided that heading periods, one week in duration, would be sufficient to indicate accurately the nature of the segregation for this character.

The results presented in Table IV show that there was no correlation between the growth-habit character and reaction to rust. The same numeric relations exist between the susceptible and resistant plants regardless of their respective times of heading. This transfer of the rust resistance of the winter parent to the progeny having the growth-habit character of the spring parent, attained the initial objective of the experiment. Several thousand rust-resistant families were obtained in the F_3 and F_4 which are being studied and tested for desirable agronomic characters in general.

These results are of particular interest not only in that they contribute to the solution of the general problem of breeding varieties of wheat resistant to rust, but also from the biological viewpoint. It is a common opinion that winter forms are more ancient or primitive than spring forms. Vavilov points out that this opinion is based on the fact that the so-called wild progenitors of our cereals are winter forms. Upon closer investigation of these wild species, however, he discovered the existence of spring as well as winter forms. He states (*18*):

> As a matter of fact, spring races in natural conditions have originated as a result of hybridization of different varieties of winter plants, and, vice versa, spring varieties could give origin to winter varieties. Both kinds of plants can be obtained synthetically one from another.

The wide genetic variability which different varieties of wheat may have for growth habit explains why spring character may be dominant over winter character and vice versa. The segregation which one would expect in a cross depends upon the factors present for the growth-habit character in the parental material. One might cross two varieties of winter wheat which from all appearances seemed to be homozygous for winter habit and in the progeny obtain some plants with the spring habit of growth. It has been shown (*18*) that spring types have appeared in the F_2 of such a cross. Likewise two spring types may be crossed and some progenies which are winter types will be obtained. This has been shown (*5*) in the case of two varieties of spring barley, in the F_3 and F_4 of which appeared several winter forms.

In view of the preceding facts and the data presented in this paper, it is not at all surprising that various workers have drawn different conclusions regarding the dominance of spring and winter characters in wheat and other cereals. The large number of F_3 selections, homozygous for heading period and varying all the way from the pure spring character to the pure winter character, demonstrates how finely the differences for growth habit may be divided. Each F_3 family (or selection) with a different heading period is of a different genetic nature. And as soon as these types become fixed, one ought to be able by intercrossing the types, to produce varying degrees of dominance of spring and winter characters.

Probably one of the most important principles that this study has demonstrated is the necessity for using known biologic forms of rust in the determination of the resistance or susceptibility of any given host. Attention was called to this principle by Stakman, Levine, and Leach (*15*) in 1919; by Hayes, Parker, and Kurtzweil (*7*) in 1920; and again by Puttick (*11*) in 1921. It has already been pointed out that previous to the discovery of the existence of biologic forms of stem rust of wheat, the breeding of resistant varieties met with failure time and again. Simply because a variety of wheat is resistant in a given locality for a period of years, there is no assurance that it will always be resistant in that locality or in any other locality in which it may be grown. And for the same reason one can not expect to prove conclusively, in an experimental plot, the resistance of any given variety, unless it is tested for resistance against all of the rust forms which exist in the area in which it is expected to be grown later. One can readily see the difficulty of producing an artificial epidemic in the field with certainty that a number of forms are present in sufficient quantity to have equal opportunity to attack all plants. Even if this were possible in a practical way, it would bring about difficulties in the synthetic production of a resistant variety. This point was clearly demonstrated in the work from which the data presented in this paper was taken.

The F_2 population was grown in the field under an artificial epidemic produced with several different biologic forms of rust. One of the parents and many of the hybrid plants were resistant to some of these biologic forms, as was proved when they were inoculated with the pure culture in the greenhouse. But in the field, all of the plants were equally susceptible, for all practical purposes. There was no method by which one could differentiate the plants one from another under this general epidemic. If a genetic study was to be made of a given number of biologic forms in their reaction on certain host plants it was evident that the work must be carried on under controlled conditions.

After the susceptible individuals have been eliminated in this manner, the general selection for desirable agronomic characters can be carried on in the field. As soon as this desired agronomic type is obtained, it will be crossed again with other varieties or selections which are resistant to other biologic forms and this process will be continued until a desirable agronomic type has been obtained which is resistant to all of the biologic forms of stem rust.

The fact that resistance and susceptibility of the host to several different forms of rust are inherited as a single genetic factor makes this cross very valuable. Kanred is known to be immune from at least 11 different biologic forms of stem rust, and, as far as tested, the immune progeny possesses all the immunity of the Kanred parent. This has further demonstrated that a variety of common wheat may be produced synthetically which will be resistant to a large number of the biologic forms of stem rust.

SUMMARY

(1) The segregation for growth-habit characters in the progeny of a cross between a winter and a spring wheat accords with Mendelian laws. The results indicate the presence of multiple factors for this character.

(2) Homozygous types for both spring and winter characters were obtained in the F_3. In the F_2, some plants appeared which were homozygous in F_3 for a heading period which was 5 weeks later than that of the Marquis (spring) parent.

(3) Kanred is an awned winter common wheat, while Marquis is an awnless spring common wheat. In the progeny of this cross there was no correlation between growth habit and presence of awns.

(4) The segregation for rust reaction to Biologic Form I in the progeny of a cross between Kanred and Marquis wheats shows a simple Mendelian ratio of approximately three immune plants to one susceptible plant. There is a clear dominance of immunity over susceptibility, since there are no intermediate types of infection with this rust form.

(5) The progeny of this cross were inoculated with several biologic forms of stem rust and show that the reaction of the host to all of these forms is inherited as a single genetic factor.

(6) In the F_3 some of the hybrid families were homozygous for the spring habit of the Marquis parent and for the rust resistance of the Kanred parent.

(7) There was no correlation between the inheritance of growth habit and the manner of reaction to stem rust.

(8) These facts further demonstrate that varieties of common wheat may be produced synthetically which will be resistant to a large number of the biologic forms of stem rust, *Puccinia graminis tritici*.

LITERATURE CITED

(1) BIFFEN, R. H.
1907. STUDIES IN THE INHERITANCE OF DISEASE-RESISTANCE. *In* Jour. Agr. Sci., v. 2, p. 109–128. Bibliographical footnotes.

(2) EVANS, I. B. Pole.
1911. SOUTH AFRICAN CEREAL RUSTS, WITH OBSERVATIONS ON THE PROBLEM OF BREEDING RUST-RESISTANT WHEATS. *In* Jour. Agr. Sci., v. 4, p. 95–104. Bibliography, p. 104.

(3) FRUWIRTH, C.
1918. DIE UMZÜCHTUNG VON WINTERGETREIDE IN SOMMERGETREIDE. *In* Ztschr. Pflanzenzüchtung, Bd. 6, p. 1–46. Bibliographical footnotes.

(4) ———
1910. ALLGEMEINE ZÜCHTUNGSLEHRE DER LANDWIRTSCHAFTLICHEN KULTURPFLANZEN. Ed. 5, xviii, 442 p., 89 fig., 8 pl. Berlin. (Handbuch der landwirtschaftlichen Pflanzenzüchtung, Bd. 1).

(5) GAINES, E. F.
1917. INHERITANCE IN WHEAT, BARLEY AND OAT HYBRIDS. Wash. Agr. Exp. Sta. Bul. 135, 61 p., 9 fig. Bibliography, p. 60–61.

(6) GARNER, W. W., and ALLARD, H. A.
1921. FLOWERING AND FRUITING OF PLANTS AS CONTROLLED BY THE LENGTH OF DAY. *In* U. S. Dept. Agr. Yearbook, 1920, p. 377-400, 9 fig.

(7) HAYES, H. K., PARKER, John H., and KURTZWEIL, Carl.
1920. GENETICS OF RUST RESISTANCE IN CROSSES OF VARIETIES OF TRITICUM VULGARE WITH VARIETIES OF T. DURUM AND T. DICOCCUM. *In* Jour. Agr. Research, v. 19, p. 523–542. Literature cited, p. 541–542.

(8) LEVINE, M. N., and STAKMAN, E. C.
1918. A THIRD BIOLOGIC FORM OF PUCCINIA GRAMINIS ON WHEAT. *In* Jour. Agr. Research, v. 13, p. 651–654.

(9) MELCHERS, Leo E., and PARKER, John H.
1918. ANOTHER STRAIN OF PUCCINIA GRAMINIS. Kansas Agr. Exp. Sta. Circ. 68, 4 p.

(10) NILSSON-EHLE, H.
1911. KREUZUNGSUNTERSUCHUNGEN AN HAFER UND WEIZEN, II. *In* Lunds Univ. Årsskr., N. F. Afd. 2, Bd. 7, No. 6, 82 p. Bibliographical footnotes.

(11) PUTTICK, G. F.
1921. THE REACTION OF THE F_2 GENERATION OF A CROSS BETWEEN A COMMON AND A DURUM WHEAT TO TWO BIOLOGIC FORMS OF PUCCINIA GRAMINIS. *In* Phytopathology, v. 11, p. 205–213. Literature cited, p. 213.

(12) SPILLMAN, W. J.
1909. APPLICATION OF SOME OF THE PRINCIPLES OF HEREDITY TO PLANT BREEDING. U. S. Dept. Agr. Bur. Plant Indus. Bul. 165, 74 p., 6 fig.

(13) STAKMAN, E. C.
1919. THE BLACK STEM RUST AND THE BARBERRY. *In* Yearbook U. S. Dept. Agr. 1918, p. 75–100, pl. 1–10 (partly col.).

(14) ——— and AAMODT, Olaf S.
1922. THE EFFECT OF FERTILIZERS ON THE DEVELOPMENT OF STEM RUST OF WHEAT. (Abstract.) *In* Phytopathology, v. 12, p. 31.

(15) ——— LEVINE, M. N., and LEACH, J. G.
1919. NEW BIOLOGIC FORMS OF PUCCINIA GRAMINIS. (Preliminary paper). *In* Jour. Agr. Research, v. 16, p. 103–105. Bibliographical footnotes.

(16) ——— PARKER, J. H., and PIEMEISEL, F. J.
1918. CAN BIOLOGIC FORMS OF STEM RUST ON WHEAT CHANGE RAPIDLY ENOUGH TO INTERFERE WITH BREEDING FOR RUST RESISTANCE? *In* Jour. Agr. Research, v. 14, p. 111–124, pl. 13–17. Literature cited, p. 122–123.

(17) ——— and PIEMEISEL, F. J.
1917. A NEW STRAIN OF PUCCINIA GRAMINIS. (Abstract.) *In* Phytopathology, v. 7, p. 73.

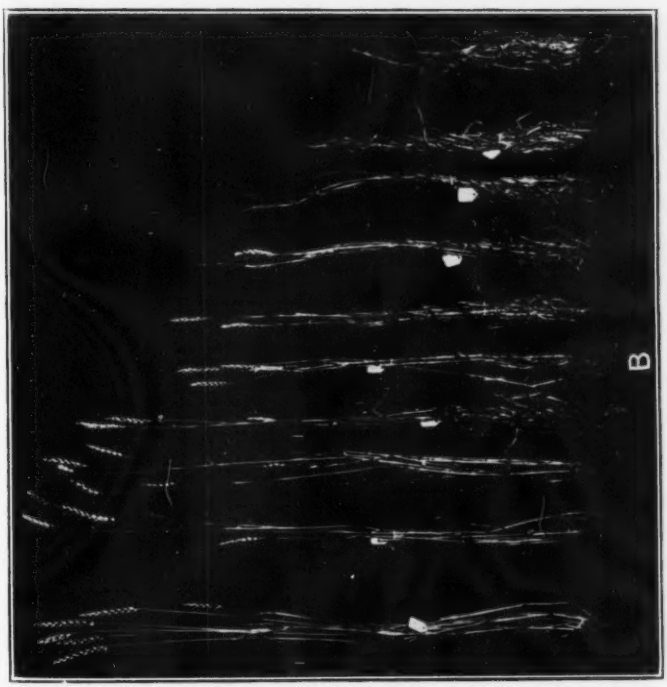
(18) VAVILOV, N. I., and KOUZNETZOV, E. S.
1921. ON THE GENETIC NATURE OF WINTER AND SPRING VARIETIES OF PLANTS. *In* Izvestii Agronomicheskogo Fakul'teta Saratovskogo Univ. (Bul. Agron. Faculty Saratov Univ.) 1921, no. 1, p. 1–25, illus. In Russian. English summary, p. 23–25.

PLATE 1

A.—Showing the difference in growth habit between Kanred winter wheat (left) and Marquis spring wheat (right) at harvest time, when both are spring sown.

B.—Showing the segregation for time of heading in the F_2 plants from the Marquis×Kanred cross, when seed from F_2 heading classes was spring sown. Left, Marquis; center, F_2 hybrids, arranged in order of heading dates, from left to right; right, Kanred.

A


B

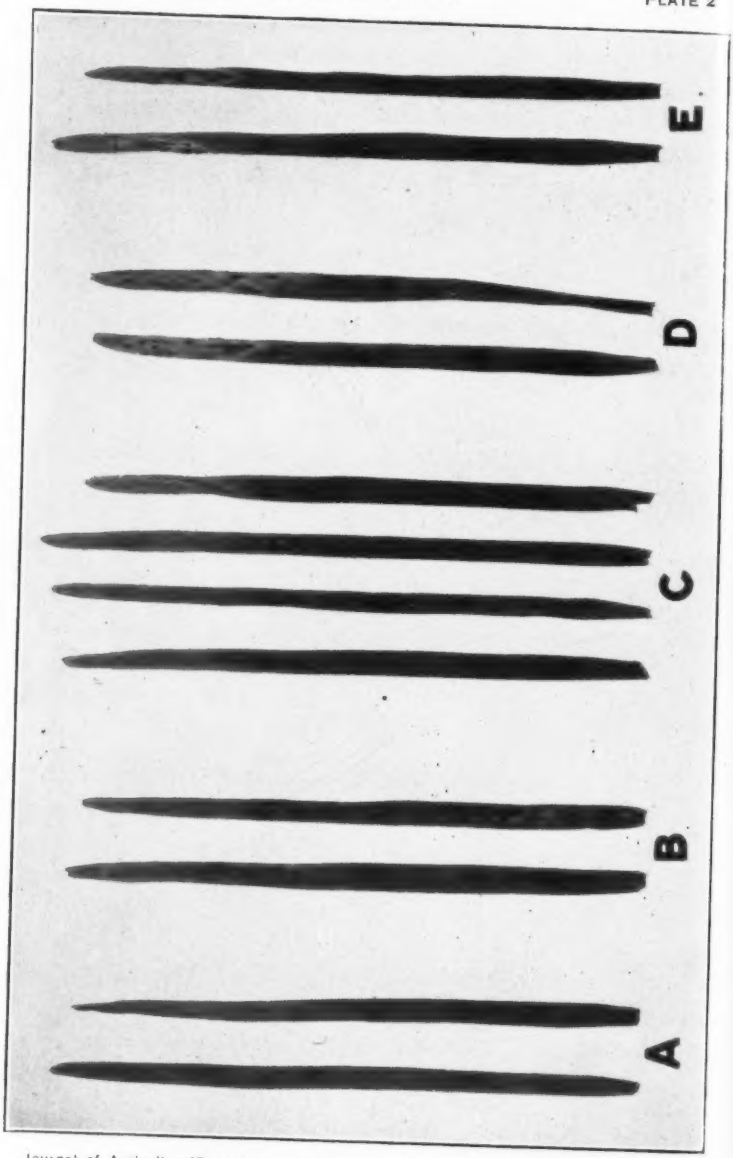

E
D
C
B
A

PLATE 2

Seedlings of Kanred, Marquis, and F_2 families of the cross between Kanred and Marquis, inoculated with a rust form from which Kanred is immune and to which Marquis is susceptible. A, Kanred, immune; B, F_2 generation, immune; C; F_2 generation, segregating for susceptibility to rust; D, F_2 generation, susceptible, E, Marquis, susceptible.

EFFECT OF ORGANIC DECOMPOSITION PRODUCTS FROM HIGH VEGETABLE CONTENT SOILS UPON CONCRETE DRAIN TILE [1]

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PREFACE

The work which is covered in the following report was begun purely as an engineering study. It arose out of the fiduciary duty of the engineer to protect the interest of his client, namely the man who ultimately pays the bill and upon whose prosperity the permanence of the whole business rests. Necessity made the scope of the investigation much broader than was at first expected. Accident drew attention to the apparent failure of a structural material under certain limited conditions which opportunity gave a chance to investigate. This does not, however, mean that the material will fail under any other conditions than those investigated. Nor does it mean that material not investigated is therefore exempt from criticism. It is believed that this investigation very materially aided a movement for the general improvement of the material investigated, not only for limited but, also, for the general application of the material.

Other material, not covered in the scope of these investigations, but used for the same purpose, is, under certain conditions, as liable to failure as is the material investigated. A general movement for its improvement is very much to be desired. A recognition of the special adaptability of each material to its own particular class of work would aid materially in stabilizing the business.

PART I. GENERAL INTRODUCTION

The extremely rapid development, particularly in the last few years, of the drainage of wet farm lands and the increasingly large investments in drainage that are being made by the farmers of this country are making necessary an intensive study of both materials and methods. Burned clay was the first material to be used extensively in this work, and by its use the early science of land drainage was developed.

The adaptability of concrete for making drain tile soon became obvious and the manufacture of concrete drain tile is now one of our well established industries. A very large proportion of the lands which may be profitably drained are either in large alluvial deposits or in immense plains left by glacial action. Under each of these conditions the formations which would carry good industrial clays are in many instances deeply buried and the farmer may have to go a considerable distance for his supplies, and pay heavy freight charges on them.

Another factor of very considerable importance is that the efficient handling of clay products requires a very considerable outlay for plant, necessitating, in its turn, a market, developed before the establishment of the plant and of sufficient size to keep the plant busy. This is impossible in the newer districts.

[1] Accepted for publication Aug. 15, 1922.

Concrete tile, on the other hand, may be made in small and inexpensive plants, adapted to seasonal business of various sorts, and the bulk of the material used is available at a comparatively low cost.

The formation of drainage districts and the digging of large outlets is of little value without complete interior drainage of the wet lands by the construction of laterals, spaced as the soil condition may require. In outlying districts the excessive cost of clay tile due to long haul prohibits its use. With this in mind it may be said that concrete, if it can be made durable, is potentially the controlling factor in the drainage development of the newer parts of the country.

Unfortunately, when first manufactured, concrete tile made a bad start. It was claimed that as most of the water got into the tile through its walls and not at the end of the tile, the more porous those walls were, the more efficient the drain would be. This erroneous idea was honestly promoted by engineers and was used as a sales argument by the manufacturers of concrete. Standard specifications at the present time permit an absorption of 10 to 12 per cent and unscupulous manufacturers have been making a product that merely holds together long enough to get it into the ground. Failure due to the breaking down of the tile has been common, but the firms manufacturing poor material have generally been of short life while those who turned out a good product have usually grown and increased their business. The result is that the average product of today is far superior to that of 10 or even 5 years ago.

It has frequently been noted that tile made by certain manufacturers, or, more correctly, the tile made by manufacturers in certain districts did not last as well as tile manufactured in other districts. The manufacturer was invariably blamed for any failure.

INVESTIGATIONS

In most average soils, well-made concrete tile appears to be permanent. As the vegetable and mineral matter of soils varies, however, the concrete tile disintegrates.

In some of the arid and semi arid districts of the West and Middle West, for instance, concrete has broken down in wet soil containing a high percentage of some alkalies, particularly alkaline sulphates. The cause is becoming fairly well understood, but the cure is still under investigation. This disintegration appears to have first been reported officially by Headden (*7*)[1] and Tannatt (*14*) in 1908. Since that time the subject has been very carefully investigated, notably by Bates, Phillips and Wig (*2*) in 1912; Wig and Williams (*16*) in 1915; Wig, Williams and Gates (*18*) in 1916; Steik (*10*) and Wig, Williams and Finn (*17*) in 1917; Steik (*11*) in 1919, and Miller (*8*) and Williams (*19*) in 1922.

The outstanding fact developed by this work is the destruction of concrete by alkaline sulphates of a comparatively high concentration in the soil water of alkaline soils.

Winter and Musselman (*21*) in 1915, and Winter (*20*) in 1917, working at the Michigan Agricultural College, investigated the solubility of concrete in water and in various acids.

The University of Washington has made tests covering the destruction of concrete by carbonic acid.

In Europe several marsh investigators have noted the disintegration of concrete in "Hoch moor." This corresponds to our "muskeg," which is

[1] Reference is made by number (italic) to "Literature cited," pp. 499–500.

composed almost entirely of moss and other low order plant accumulations, without inwashed soil or lime.

Vogler (*15*) in his "Grundlehren der Kulturtechnik," published in 1909, draws a strong distinction between low moor and high moor, repeatedly affirming the resistant quality of cement tile in low moor and its destruction in high moor.

Tacke (*13*), in 1910, published a paper on the substances in peat which would probably be destructive to concrete. He mentions the disintegration of concrete in a moor containing as high as 17 per cent of iron pyrite. He also discusses the probable destruction from humic acids of concrete in high moor and its permanence in low moor.

Bersch (*3*) in his "Handbuch der Moorkultur," published in 1909, makes the same distinction between low and high moor as does Vogler, and draws the same conclusions regarding the durability of the concrete tile in the two classes of peat.

None of these authorities followed up his observations by any published research results, but the behavior of concrete tile in peat was considered of such importance that a subcommittee of the German Committee on Reinforced Concrete was assigned to the task of making investigations. Their work was interrupted by the war.

In this country previous to 1921, if there had been any suspicion of destructive effect on concrete tile due to weak soil acids, no report had been made of any investigations induced by such a suspicion. Wig, Williams and Finn (*17*) in 1917, while investigating the effect of alkali on tile, noted a disintegration that took place on one of their tile lines at Columbia, Mo., where tile were laid in supposedly neutral soil as a control against the disintegration of similar tile laid in alkaline soil. They say in their report:

> An exceptional condition has arisen at this project, presumably caused by some local action, in that the tile of series 1 to 16, excepting series 5 (tar coated), showed evidences of disintegration on the lower outer surface, indicated by the apparent dissolving away of cement leaving the sand grains coated with a brown stain.

The tile at Columbia were laid in mineral soil overlaid by 12 to 15 inches of black soil.

Williams (*19*) in 1922, reports on the same tile that in all cases except those which had been in the ground only one and two years, and those which were tar coated, the tile were stained and pitted.

Alway (*1*) in 1922, refers to the work of Tacke at some length. He questions the probabilities that the breaking down of the concrete tile is due to the action of organic acids or that concrete tile break down in peats containing a high percentage of lime. He says:

> Humic acids are not carried in the bog water of high lime peats. These acids are more or less soluble in pure water and in weak mineral acids, as phosphoric and boric, but insoluble in hydrochloric and sulphuric acids. With soluble compounds of calcium, magnesium, iron and aluminum, they form insoluble compounds, so called humates which are insoluble in water as well as in moderately concentrated alkali solutions.

Soluble sulphates, particularly those caused by the breaking down of iron pyrite (a common condition in acid peat bogs) seem to him to be the most probable cause of disintegration, but he also includes hydrogen sulphid and alkali waters.

Stewart (*12*), collaborating with Doctor Alway, and writing in the same publication, makes a direct statement along the lines suggested by Doctor Alway's paper.

In February, 1921, the writer (*4*) offered the theory that concrete tile were liable to disintegration in any soil carrying a high percentage of organic matter. This was followed in July of the same year by a further statement (*5*) to the same effect.

In addition to the authorities quoted, numerous observers in the last two years have reported a breaking down of concrete tile lines in soils high in organic matter. None of the authorities quoted, however, either in this country or Europe, have followed up their observations with exhaustive research which they have later reported. Nor have any of them considered it probable that concrete tile would break down in soils carrying a high percentage of lime. Consequently in the work covered by these investigations, this point has been especially recognized and covered.

UNIVERSITY MARSH

A tract of 110 acres of peat marsh is located on the experimental farm of the University of Wisconsin. For the past 10 years this land has been used for experimental purposes in drainage. This area, which at one time was a swampy bay of Lake Mendota, is generally known as University Marsh. Most of its surface is a little above the lake and the soil consists of fibrous peat 2 to 6 feet deep, underlain by sand and clay. In the deeper parts of the marsh there is a bed of marl between the peat and the mineral soil below. The marl bed varies considerably in thickness up to a maximum of about 18 inches, and around its margin frequently blends with, and is interlaid by sand. Since diking, various types of drainage have been worked out, improvements and changes being made as their value was demonstrated.

On the higher side of the marsh are a number of high morainal hills from which the surface water of about 400 acres drains down. Heavy seepage also works into it from below, expecially in the sandy portion. This is sufficient if the stream is concentrated into a pipe to lift the water 2½ feet above the marsh surface.

From the beginning, this experimental work on the marsh has been under the direction of E. R. Jones, professor of agricultural engineering at the University of Wisconsin and State drainage engineer. During the fall of 1919, and the season 1920, the work was under the direct charge of the writer, whose principal function was a determination and compilation of data on the physical change in the marsh brought about by the various stages of drainage and cultivation.

Part of the work consisted of an examination of the tile lines themselves. This was done by groups, taking as a group a series of tile having a common outlet and laid at the same time and under similar conditions. On each group several pits were dug for the purpose of examination. If no unusual conditions were disclosed, it was assumed that none had developed. If, however, any unusual condition were disclosed, more pits were dug for the purpose of determining whether or not the unusual conditions were inherent in the group.

DISINTEGRATED TILE

Seven lines of tile, two of which were concrete, were laid by students in May and June, 1914. Lines 5 and 7 were of concrete. In December, 1919, on opening these two lines, the tile were found to show signs of failure.

More pits were opened, and it was discovered that the entire lines were badly disintegrated, decay being greatest at the upper end and farthest away from the pump house. It was at first thought that the tile might have broken down, owing to bad workmanship, but this was disproved when it was found that at the extreme upper end of the tile lines, where rotted muck had flowed in and partially filled the tile, the tile had been protected, and had not decayed. It still bore the marks made by the mold, and, upon breaking, the interior of the tile wall appeared to be in perfect condition. The surface of the tile, both inside and outside, was rough, due to the grains of sand and gravel falling away. Inside the disintegrating layer, the tile was discolored for about $\frac{3}{32}$ of an inch, but appeared to be dense, while a thin layer in the center of the wall was unaltered. This last fact shows that the tile had not broken down due to the passage of waters through the walls, but to solvent action upon the walls themselves. Disintegration was greatest on the outside of the tile and at the ends and much greater on the top than on the bottom. Disintegration on the inside of the tile was greater at the top than on the bottom, and was not greater at the water line, except at the joints, where it met heavy disintegration from the outside.

Since the tile showed signs of good workmanship, it was assumed that the disintegration must have been due to the solvent action of some substance present in the soil.

Correspondence was begun and the literature searched to secure information which would throw some light on the reason for the disintegration. The most probable solution of the difficulty was first presented by Prof. H. B. Roe, of the University of Minnesota, who cited the destruction of concrete tile in his State by the action of sulphate salts. This possibility was further investigated and talked over with chemists. The conclusion tentatively arrived at was that the disintegration was caused by sulphates produced by the decomposition of proteins in the peat. This solution seemed satisfactory.

Work on the marsh was discontinued at this point because of cold weather. The compilation of data could not go ahead until more field work was done and opportunity was taken to test out the assumed presence of sulphates in the marsh and their effect on new tile.

PART II. PRELIMINARY STUDIES

LABORATORY INVESTIGATIONS

With the advice and assistance of Prof. E. Truog and E. J. Graul of the Soils Department, laboratory studies were made, beginning in February, 1920. A cement tile company furnished new, uncontaminated tile for the tests. These tile were machine made, very dense, steam cured, and three months old at the time of the tests.

MARSH WATERS

No sulphur in the form of sulphates could be detected in water from the marsh by the addition of barium chlorid to a hot solution slightly acid with hydrochloric acid. The assumption that the disintegration was due to the presence of sulphate salts was therefore unfounded, and the whole cause of the destruction still remained obscure.

The next step was to find actually what was in the marsh waters and if those marsh waters would dissolve the tile. Iron and aluminum were

thrown down in considerable quantity by ammonia. Lime magnesia was also thrown down by ammonium carbonate.

Lime in the water was determined by the following method: To 100 cc. of the water a few drops of HCl were added to dissolve anything which might be held in suspension, and then 5 gm. of ammonium chlorid. Ammonium hydroxid was added in sufficient quantity to make the solution strongly alkaline and acetic acid to make the solution just slightly acid. After boiling, the iron, aluminum, and phosphorus were filtered off and the precipitate carefully washed. To the boiling filtrate and washings, 10 cc. of 10 per cent solution of ammonium oxalate were added, then dilute ammonia until the solution was slightly alkaline. After digestion the solution was allowed to stand over night, then filtered on ash-free filter papers and washed with hot water.

The precipitate on the filter paper was then dissolved with 10 per cent solution of sulphuric acid. Next, 2 cc. more of H_2SO_4 was added, plus enough water to bring the volume to 200 cc. The solution was then warmed and titrated with $\frac{1}{10}$ normal solution of potassium permonganate. Lime was calculated on the basis of 1 cc. of solution (.0028 gm. of CaO). The results of these tests are given in Table I.

TESTS WITH CARBONIC ACID

Carbonic acid was next suspected as being the solvent. A quantity of distilled water was saturated with pure carbonic acid. Weighed fragments of tile of approximately the same shape and size and from which all loose particles were removed were placed in 500 cc. bottles and 475 cc. of the various waters added. The bottles were then tightly corked, placed in a revolving shaker machine and agitated 24 hours intermittently for 3 days. Duplicate samples of each were run. It was attempted to determine the solubility of the tile by determining the amount of lime originally in the water and in the sample run. It was found that lime was actually thrown out of solution from the waters taken from the bog and that the carbonated water did not contain nearly as much lime as did the distilled water. The results are shown in Table I.

TABLE I.—*Grams of CaO per liter, in marginal and bog waters in their original condition, as collected in February, and in these and in distilled and carbonated waters after agitating 3 days with similar pieces of new tile*

Test No	Original water.		Waters agitated with tile.			
	Marginal.	Bog.	Distilled.	Carbonated.	Marginal.	Bog.
	Gms	*Gms*	*Gms*	*Gms*	*Gms*	*Gms*
1	0.0896	0.0854	0.2156	0.1120	0.0651	0.0945
2	.1120	.0857	.2226	.0476	.0588	.0756
3	.1106	.0868	.1365	Broken.	.0525	.0357
4	.1036	.0784				
5	.1008	.0770				
Average	.1033	.0826	.1918	.0798	.0588	.0686

In the agitated waters it will be noted that some of the tests in a series show a marked variation from others in the same series. This was attributed to the fact that the samples of tile were probably far from uniform.

Two outstanding facts were indicated. The first was a greater solubility of the tile in distilled water than in either the carbonated or bog water. The second was that though pieces of tile had been agitated for 3 days in water from the margin of the marsh, the quantity of lime actually in the water was less than in the beginning.

This result showed that the original premises were not well founded. They were either incorrect or something had been omitted from them. Within the power of the test to show it, carbonic acid was not causing the destruction of the tile; neither was the marsh water, apparently.

TESTS FOR ALKALI

There appeared to be no explanation for the results given in the Table I until it was suggested that perhaps the marsh waters did not actually contain free carbonic acid and that the tile, even after a lengthy curing, might contain free alkali. To test this, a quantity of tile was powdered and to it a small amount of distilled water was added which was immediately poured off and filtered. It gave a powerful reaction with phenolphthalein, showing that the tile was not only alkaline but that a considerable quantity was soluble in water. A quantity of the powdered tile was boiled in distilled water, filtered, and while still hot 100 cc. of the filtrate measured. This gave 3.582 gm. of residue on evaporation, a surprising percentage considering the age of the tile.

The marginal and bog water was then tested on the assumption that they contained free organic acids. Methyl orange showed that they did not. They were then titrated with standard sulphuric acid solution, $\frac{1}{14}$ normal strength, using methyl orange as an indicator. The test disclosed strong alkaline reactions, showing unneutralized alkalies of the strength indicated in Table II.

TABLE II.—*Showing the amount of $\frac{1}{14}$ normal acid solution required to neutralize the free alkali in marginal and bog water and its equivalent in CaO per liter of water*

Equivalents.	Marginal water.	Bog water.
Cubic centimeters of one-fourteenth normal solution used...	15.30	14.80
CaO equivalent per liter, gm.....	.1530	.1480

The contradictory results obtained were now explained on the basis of the precipitation of calcium carbonate formed from the more soluble calcium bicarbonate by the free alkali of the tile taking away one-half of the carbonate radicle.

However, this did not make the explanation of the disintegration of the tile any clearer; instead, it became still more obscure.

COMPARISON OF OLD AND NEW TILE

The results of the tests using the new tile being apparently so different from what had actually happened in nature, it became necessary to compare the old and new tile in order to determine whether or not the new tile differed in any material degree from that which originally went into the drains.

One entire new tile was taken from the marsh, wiped with a towel, and weighed while still wet. It was then dried to constant weight in an electric oven at 110° C. and again weighed. The loss was 11.90 per cent, representing the proportion of water contained.

Similarly two new pieces of new tile were weighed in their natural air-dry condition, dried in an electric oven at 110° C., weighed again, boiled for two hours in water, and weighed again. The results are tabulated in Table III.

TABLE III.—*Percentage of water absorbed by old and new tile*

Samples.	Weight at 110° C.	Water absorbed in ground.	Water absorbed from air.	Water absorbed on boiling.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Tile from marsh	100	11.90	.....	.....
New tile, sample (a)	100	.....	1.551	6.631
New tile, sample (b)	100	.....	1.545	7.095

From this table it will be seen that the tile which was taken from the marsh had nearly double the porosity of the new tile. How much this porosity was altered during the time it was buried in the ground it is impossible to say. From the maker's statement there is no doubt that the tile was less carefully made than that now turned out by the same manufacturer. An absorption of 12 per cent would indicate a good average tile at the time these were made, and is about the average of material turned out by the less careful manufacturers at the present time.

COMPARATIVE ALKALINITY OF TILE

The next step was to compare the alkalinity of the old and new tile. It would be natural to assume that any free alkali would be very quickly neutralized after the tile was placed in the ground. A quantity of the old tile and of the new tile were pulverized and 2 gm. taken from each. Then 200 cc. of distilled water was added to each sample and phenolphthalein used as an indicator. The solution was titrated by adding at successive intervals $\frac{1}{14}$ normal solution of sulphuric acid, extreme care being used, particularly toward the end of the operation, not to permit the solution to contain any free acid and so expel carbonic acid. The operation was carried on over 2 days, titrating about every half hour with results as shown in Table IV.

TABLE IV.—*Amounts of $\frac{1}{14}$ normal acid solution required to neutralize free alkali in 2 gm. each of old and new tile, and percentages of free alkali indicated*

Item.	Old tile.	New tile.
Grams of tile used	2.00	2.00
Cubic centimeters of $\frac{1}{14}$ H_2SO_4 solution used	17.70	40.50
Equivalent grams free CaO or equivalent	.0354	.0810
Per cent free CaO or equivalent	1.770	4.050

The results given in the preceding table are very remarkable. Not only did the new tile after a presumably thorough curing still contain 4 per cent of free alkali, but the old tile after 5 years in the ground, during which time it was partially destroyed, still contained nearly half as much. The importance of the fact indicated can hardly be overestimated. It will be discussed later.

SOLUTION IN HCl

New tile in concentrated HCl was then tested. Strong evolution of bubbles showed the presence of a considerable percentage of carbonate. The dried filtrate was ignited and treated again with acid. The exact percentage of solubility is shown by Table V.

TABLE V.—*Percentage of new tile soluble in concentrated HCl*

Constituent.	Percentages.
Insoluble silica	47.42
Total soluble	52.58
Soluble silica	3.40
Total solubles other than silica	49.18

ULTIMATE SOLUBILITY IN ORGANIC ACIDS

In order to ascertain the percentage of the tile which might be ultimately soluble in organic acids and to establish a relation between it and the aggregate used, an acid of low hydrogen-ion concentration was chosen, namely, quarter strength acetic, and samples of the old and the new tile and the aggregate from which the tile were made were treated with it. The acid used was supposed at the time to be full strength, but was later found to be about 85 per cent. From each sample previously dried in the electric oven, 5 gm. was taken and boiled for 10 minutes in the dilute acid and the residue weighed after drying in the electric oven at 110° C. The results are given in Table VI.

TABLE VI.—*Percentages of old tile, new tile, and aggregate soluble in 21 per cent strength acetic acid*

Item.	Old tile.	New tile.	Aggregate.
Grams taken	5.00	5.00	5.00
Residue	3.3090	3.2777	3.5152
Loss	1.6910	1.7223	1.4848
Per cent soluble	33.82	34.45	29.69

ANALYSIS OF AGGREGATE

A screen analysis of the sand and gravel aggregate used in the manufacture of the tile gave:

Grade:	Per Cent of Total.
Coarser than 10 mesh	46.6
10 to 20 mesh	13.4
20 to 40 mesh	18.2
40 to 60 mesh	12.2
60 to 80 mesh	4.8
80 to 100 mesh	1.6
100 mesh	2.4
	99.2

Tomlinson[3] has calculated the mineralogic proportions in Waukesha sand by relative density and miscroscopic count, proportions of carbonates and of quartz in different sizes of Waukesha sand, as follows:

Group:	Carbonates.	Quartz.
Coarser than 10 mesh	72.1	1.5
10 to 20 mesh	72.1	7.0
20 to 40 mesh	55.7	35.4
40 to 100 mesh	36.9	58.1

Proportion of Mineral groups in Waukesha sand

Group:	Per Cent.
Igneous rock	0.42
Shale group	....
Quartz group	32.31
Dolomite group	65.37
Feldspar	....
Heavy minerals	.83
Not sorted	1.07
	100.00

TESTS OF CEMENT

Both the old and the new tile had been made with a slag Portland cement of average chemical composition. This cement was also treated with acetic acid to ascertain its solubility. It showed a trace of carbonic acid bubbles.

A quantity of the cement was mixed into a thick paste with water, thoroughly worked and rolled into balls by hand, then flattened on glass, made into patties and allowed to set one day under a moist cloth. At the end of that time, the patties had set firmly and showed no signs of malformation, swelling, or shrinkage cracks. Boiled one hour in water, they showed no signs of failure.

Some of the patties were allowed to set three days in water and at the end of that time appeared to be in perfect condition. They were then powdered, and 2 gm. dried at 110 C°., were treated with 21 per cent strength acetic acid. Other patties, made in a similar way at Minnesota, were allowed to set in water for three months, and then five months in air at a temperature averaging 75° F. These were powdered and treated like the others. The first test showed no evolution of bubbles, but the second gave bubbles in considerable amount, showing that the cement had carbonated during the eight months set. The result of the two tests are tabulated in Table VII.

[3] TOMLINSON, C. W. UNPUBLISHED THESIS. Univ. of Wis., Col. of Engin., 1915.

TABLE VII.—*Solubility of cement set 4 days and 8 months in acetic acid of 21 per cent strength*

Item.	4-day set.	8-month set.
Weight of sample (gm.)	2	2
Weight of residue (gm.) (a)	.559	0.4290
Weight of residue (gm.) (b)		0.4665
Percentage of solubility (a)	72.02	78.55
Percentage of solubility (b)		76.68

The two tests show an average increase in solubility of 5.50 per cent. If this is to be explained on the basis of calcium hydroxid becoming carbonated during the eight months it would indicate a proportion of unneutralized lime in the freshly set cement equal to 25.8 per cent.

ANALYSIS OF CEMENT

A cement company very kindly furnished the following analysis of their cement and a report of physical tests.

Chemical analysis of cement, average of daily analyses, March, 1920

	Per cent.
Silica (SiO_2)	22.04
Oxid of Iron (Fe_2O_3)	3.30
Alumina (Al_2O_3)	5.70
Lime (CaO)	62.64
Magnesia (MgO)	3.73
Sulphuric Acid (SO_3)	1.23
Loss on Ignition	.50

Physical tests of the same cement, average for February, 1920

Fineness:	
Passing 200-mesh sieve	81 per cent.
Setting time:	
Initial set	2 hrs. 45 min.
Final set	5 hrs. 5 min.
Tensile strength:	
1 part cement to 3 parts standard Ottawa sand—	
3 days (1 day in moist air and 2 days in water)	239 lbs.
7 days (1 day in moist air and 6 days in water)	322 lbs.
28 days (1 day in moist air and 27 days in water)	420 lbs.

RESULTS OF PRELIMINARY STUDIES

Up to this point the work done may be considered as preliminary studies, though that was not the intention when some of the tests were begun. The principal points brought out may be enumerated as follows:

(1) The alkalinity of the marginal and bog waters in February.
(2) The powerful alkalinity of the tile even after 5 years in the drain.
(3) The similarity of the old and new tile except in the matter of density.
(4) The solubility of the thoroughly matured tile in weak organic acid.
(5) The absorption of CO_2 during long a period of curing.

Analyses of American Portland Cements (from "Portland Cement")

Made from—	Where made.	SiO_2.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	K_2O.	Na_2O.	SO_2.	Loss.
Cement rock and limestone.	Nazareth, Pa.	19.92	2.28	7.52	62.48	3.19	0.52	0.66	1.51	1.46
	.....do.	21.14	2.30	6.94	63.24	3.26	.36	.51	1.12	1.24
	Bath, Pa.	19.64	2.80	7.52	62.31	3.04	n. d.		1.60	1.48
	Alpha, N. J.	21.82	2.51	8.03	62.19	2.71	n. d.		1.02	1.05
	Northampton, Pa.	21.94	2.37	6.87	60.25	2.78	.61	.87	1.38	3.55
	Coplay, Pa.	22.26	2.10	5.36	63.32	3.81	n. d.		.89	1.24
	Omrod, Pa.	22.20	2.27	6.69	62.61	3.00	.32	.61	1.32	1.56
	Martins Creek, Pa.	20.23	2.50	7.12	62.94	3.38	n. d.		1.45	1.25
	Reading, Pa.	24.16	1.45	5.10	62.95	3.12	.21	.50	1.35	1.40
Limestone and clay or shale.	Ban City, Mich.	20.72	2.85	7.17	62.64	1.97	.48	.12	1.42	2.58
	Wellestone, Ohio.	21.84	5.05	6.77	62.66	.80	n. d.		1.24	.....
	Chanute, Kans.	20.74	3.72	7.06	62.76	1.78	.41	.23	1.12	1.40
	Ada, Okla.	12.28	3.20	6.36	59.66	3.11	.80	.25	1.40	2.82
	*Stroh, Ind.[1]	21.78	2.65	7.31	62.35	2.88	0.47		1.78	.78
	*Glens Falls, N. Y.	21.50	10.50		63.50	1.80	.40		1.50	n. d.
	Aisen, N. Y.	23.94	3.20	5.62	62.32	1.77	n. d.		.90	1.68
	Fordwick, Va.	21.31	2.81	6.54	63.01	2.71	n. d.		1.42	2.01
	Davenport, Calif.	25.38	1.20	3.34	62.96	1.20	n. d.		.35	4.58
	Cement, Calif.	22.34	3.30	7.00	60.72	1.30	n. d.		1.05	2.54
	*Baker, Wash.	24.63	8.56		62.88	1.60	n. d.		1.33	n. d.
	St. Louis, Mo.	23.12	2.49	6.18	63.47	.88	n. d.		1.34	1.81
	Demopolis, Ala.	19.36	4.10	9.18	63.20	1.16	n. d.		1.18	1.12
	*Portland, Colo.	21.88	2.85	7.14	64.94	Trace.	1.18		.73	1.08
Marl and clay.	*Middlebranch, Ohio.	21.24	4.14	7.85	63.22	.28	.68		1.11	1.32
	*Coldwater, Mich.	21.22	3.83	7.51	63.75	.82	n. d.		1.58	1.02
	Sandusky, Ohio.	21.93	2.35	5.99	62.92	1.10	.63	.27	1.55	2.92
	*Bronson, Mich.	22.90	3.60	6.80	63.90	.70	1.10		.40	.60
	*Harper, Ohio.	21.30	2.00	6.95	62.50	1.20	n. d.		.98	4.62
	*Warners, N. Y.	22.04	3.41	6.45	60.92	3.53	n. d.		1.25	.....
Limestone and blast furnace slag.	Chicago, Ill.	22.41	2.51	8.12	62.01	1.68	n. d		1.40	1.08
	.....do.	23.06	2.88	8.16	62.10	1.88	.36	58	1.57	.....

[1] Analyses made by Richard K. Meade, with the exception of those designated *.

The average is represented by the following:	Per cent.
Silica	22.0
Alumina	7.5
Iron oxid	2.5
Lime	62.5
Magnesia	2.5
Sulphur trioxid	1.5

PART III. DEFINITE RESULTS

In the preliminary work where tests were made with tile, the proportion of tile to water was far in excess of the proportion between the tile in a marsh, and the marsh itself was always sufficiently high to make the combined solution strongly alkaline. In all later work the aim was to reverse the proportions so as to make the influence of the marsh predominate. The marsh water, too, taken in the month of February, was alkaline. It became necessary to determine if the water in the marsh remained alkaline under the influence of warmth and if the tile were acted upon by a large excess of solutions produced under warm conditions.

TEST WITH SURPLUS OF BOG WATER

The results of the tests with a comparatively large piece of tile in a small quantity of water being unsatisfactory, due to the excessive alkalinity of the tile, another scheme was devised which was intended to subject tile to a large quantity of water. In order to increase the rapidity of action, the surface of the tile was increased as much as possible by powdering the tile. From this powdered material 50 gm.

was placed in a 1-inch glass tube, 10 inches long, stoppered at each end, a glass tube giving ingress and egress at bottom and top. The inlet tube at the bottom was curved downward on the inner end to prevent the tile grains from escaping downward through the tube. Peat taken from a depth of 5 feet in the same pit from which the bog water was taken was mixed with distilled water in a 2-gallon glazed earthen jar having an orifice near the bottom. A glass tube led through this orifice and connected on the inside with a long inverted "U" on the bottom of which was a glass funnel covered with muslin as a filter. The tube through the orifice connected on the outside with a filter made of a 1-inch stoppered glass tube in which was asbestos pulp packed above glass wool. The object of the filter was to prevent the escape of any trace of solid matter into the powdered tile. At the upper end, the tube containing the powdered tile connected with a glass tube which led downward into another weighed filter made of a porcelain "gooch" in which ⅛-inch of shredded asbestos had been packed. A pump was connected on below the "gooch" to draw the water through the system from the mixture of peat and water in the earthen jar. The last filter was carefully weighed after drying it in an electric oven at a temperature of 110° C. In action the pump sucked the water from the jar through the first filter, through the powdered tile, and through the second filter, which caught all fine sediments carried upward by the descending current. It was the intention to weigh the filter and the contents of the tube to ascertain the percentage of loss in weight, if any.

SETTING OF POWDERED TILE

The experiment as outlined was a failure, but several most interesting facts were discovered. At the end of the first day the apparatus began to work badly and more force had to be put on the pump to draw the water through. At the end of two days, the apparatus refused to work at all. It was taken apart and in the "gooch" was found a considerable thickness of brown semigelatinous rubbery mass completely clogging it. Where the water from the peat had passed upward through the powdered tile, that also had been stained brown. The "gooch" was disconnected and the water from the tile was led downward through a long tube acting as a siphon into a large glass container. At the end of another 24 hours the flow had entirely stopped and the powdered tile had "set" firmly.

A sample of powdered tile was moistened with water and allowed to stand overnight, and found to be set firmly in the morning. The same was done with the old tile, powdered, with like result, though the set was not so strong. This was repeated with both tile, using a large excess of carbonated water, the powdered tile being shaken up in the water. Both, on settling, set much more strongly than before.

10-DAY PEAT CULTURES

To overcome this difficulty of the powdered tile "setting" another scheme was devised. Peat from the top of the University Marsh, which gave a slightly acid reaction, peat from the pit, which was alkaline, and peat from north central Wisconsin, which was strongly acid, were placed in glazed earthern jars and distilled water added. The jars were then allowed to stand 10 days in a warm room and the water tested for acidity. All were acid, and in the following proportions when titrated with $\frac{1}{14}$ normal hydroxid solution, using phenolphthalein as an indicator.

TABLE VIII.—*Showing amount of $\frac{1}{14}$ normal alkaline solution required to neutralize acidity of 100 cc. water from 10-day cultures of surface and deep peat from University Marsh, and northern acid peat; also its equivalent in grams of free lime per liter*

Water sample (10-day culture).	$\frac{1}{14}$ normal solution used.	Equivalent per liter to CaO.
	cc.	*Gm.*
Surface peat (a)	0.55	0.0110
Do (b)	.60	.0120
5-inch peat (a)	.45	.0090
Do (b)	.50	.0100
Northern acid peat (a)	6.75	.1350
Do (b)	6.80	.1360

TESTS WITH 10-DAY CULTURES

Duplicate bottles were prepared containing 2 gm. each of new tile and to each was added 400 cc. of distilled water. The same was done with carbonated water, marginal water, bog water, surface, deep peat, and northern peat culture. These were immediately tightly stoppered, placed in a shaker machine, and agitated continuously 54 hours.

It will be noted that only the northern peat water was in sufficient quantity to neutralize the free alkali in the 2 gm. of tile. This was further indicated by the rate of settling of the solids held in suspension. While all the other bottles, even the carbonated water, settled overnight, the acid peat water was still turbid after 3 days and showed distinct layers of colloidial material slowly settling in the liquid above the sediment in the bottom.

Hall (*6*) has shown that the alkali earth, particularly the carbonates, have a strong flocculating action assisting in the deposition of sediments. The results just obtained indicate that the products of organic decay have an even more powerful effect in retaining them in suspension.

TABLE IX.—*Residue left after treating 2 gm. of tile with 400 cc. of water as in Tables I and VIII (agitated 54 hours and settled 14 hours)*

400 cc. of—	Weight of tile used.	Weight of residue.	Soluble.	Increase.
	Gm.	*Gm.*	*Per cent.*	*Per cent.*
Distilled water (a)	2	1.8796	6.02	.....
Do (b)	2	1.8532	7.34	.....
Carbonated water (a)	2	1.8983	5.08	.....
Do (b)	2	1.8727	6.36	.....
Winter waters:				
Marginal water (a)	2	2.0270	.....	1.35
Do (b)	2	2.002	.....	.01
Bog water (a)	2	2.0100	.....	.50
Do (b)	2	2.0119	.....	.559
10-day cultures:				
Surface peat (a)	2	2.0965	.....	4.82
Do (b)	2	2.0960	.....	4.80
Peat 5 feet deep (a)	2	2.0090	.....	.45
Do (b)	2	1.8948	5.26	.....
Northern peat [1] (a)	2	2.2007	.....	10.03
Do (b)	2	2.0885	.....	4.12

[1] The duplicates of the last two pairs showed distinct differences in the color of their filtrates; the darker filtrate passing through much more rapidly, possibly due to a thinner filter, and carrying colloidal material with it.

SOLUBILITY OF TILE IN DECARBONATED PEAT WATER

Next, 400 cc. of the most acid peat water was taken, from which all carbonic acid had been removed by drawing through it air passed through sodium hydroxid, and 2 gm. of powdered tile were added. The solution was then agitated in the shaker machine, the residue filtered out on a dried, weighed, ashless filter, dried in an electric oven to constant dryness, weighed, and then residue and filter agitated for 14 hours in 400 cc. of carbonated water.

TABLE X.—*Results of agitating 2 gm. of tile with acid peat water and treating the residue with carbonic acid water* [1]

Item.	Weight after treating with acid peat water.	Weight of residue treated with carbonated water.
Original sample.....(gm.)..	2.0000	2.1288
Residue.....(gm.)..	2.1288	1.9129
Per cent increase.....	6.44	.....
Per cent decrease from sample treated with peat water....	.....	10.14
Per cent decrease from original.....	.....	4.25

[1] The filtering of the solution of tile with peat water was carried on with considerable difficulty, owing to the colloidal nature of the products, yet the solution showed only a slight turbidity.

INCREASING ACIDITY OF ROTTING PEAT

In order to ascertain whether the process of decay increased the percentage of acid in solution or not, the acidity of the water on the peat cultures was tested after 20 days and compared with the 10-day culture. Conditions in the northern peat culture had been altered by the addition of more water, so that was excluded from the calculations.

A titration of 100 cc. of the water with $\frac{1}{14}$ normal solution of sodium hydroxid was made, using phenolphthalein as an indicator.

TABLE XI.—*Amount of $\frac{1}{14}$ normal alkaline solution required to neutralize the acidity of 100 cc. of water from 20-day cultures of surface peat and deep peat from University Marsh and the equivalent in grams of free lime per liter*

Sample taken.	Amount of $\frac{1}{14}$ solution used.	Equivalent to CaO per liter.
	cc	*Gm.*
Surface peat (a).....	2.95	0.0590
Do (b).....	3.15	0.0630
5 feet peat (a).....	3.50	0.0700
Do (b).....	3.30	0.0660

TABLE XII.—*Summary of Tables X and XI, showing acidity of 10-day cultures equivalent to grams of free lime per liter of water*

Sample taken.	Original state.	CaO equivalent.	
		10-day culture.	*20-day culture.*
Surface peat (a)	Faintly acid	0.0110	0.0590
Do (b)	....do	.0120	.0630
Peat 5 feet deep (a)	Alkaline	.0090	.0700
Do (b)	....do	.0100	.0660
Northern peat (a)	Acid	.1350	.....
Do (b)	....do	.1360	.....

During the late winter of 1922, with the assistance of Mr. R. C. Reck, chemist of the drainage laboratory, University Farm, St. Paul, a series of determinations were run, using peat solutions derived from Coon Creek peat, which was alkaline. Distilled water was put on a quantity of the deeper peat from the Coon Creek experimental tracts. The water was tested one-half hour after being put on the peat, again at 10 days, and again after 30 days, the 30-day test water being free from carbonic acid. The results of the tests, in which methylorange was used as an indicator, are given in Table XIII.

TABLE XIII.—*Determinations of relative alkalinity or acidity of water from Coon Creek peat at different ages*

Age of test water.	Test No.	Amount taken.	$\frac{N}{20}$ solution used.	CaO equivalent per liter.
		cc.	*Gm.*	*Gm.*
1st day	1	25	0.52	0.0292
Do	2	50	1.04	.0292
10th day	1	Neut.	.....	.....
Do	2	Neut.	.....	.....
30th day	1	25	.40	.0224
Do	2	25	.35	.0196

In order to ascertain if any effect were produced on the concrete tile by a weak solution of organic acid free from carbonic acid alternating with carbonic acid, 2 liters of the peat solution were taken and air passed through for 24 hours. The air was first drawn through moist sodium hydroxid to eliminate CO_2. The water was then tested for acid, with results given in Table XIII. Two flasks were then taken and 400 cc. of the peat water placed in each. One gram of oven-dry, powdered tile was then added to each bottle. The bottles were then corked and agitated for 48 hours. The solutions were then filtered on weighed ashless filters and the residues dried and weighed. The residues, which were not removed from the filter, were replaced in the flasks and to each was added 400 cc. of distilled water containing pure carbonic acid. This carbonic acid water was tested and found to be 0.016 normal strength. The solutions were then agitated for 24 hours and the residue dried and weighed. The residue was then treated again with peat water and carbonic acid water, agitating 24 hours. The results are tabulated in Table XIV.

TABLE XIV.—*Effect on concrete by treating repeatedly with weak peat water and with CO_2 water*

Item.	Sample 1.	Sample 2.
Original weight (gm.)	1.0000	1.0000
Residue after treatment with 400 c. c. of peat water (gm.)	.9684	1.0464
Residue after treatment with 400 c. c. of CO_2 water 0.016 normal strength (gm.)	.8367	.9120
Residue after second treatment with peat water (gm.)	.7879	.9167
Residue after second treatment with CO_2 water (gm.)	.7843	.8890
Total net loss (gm.)	.2157	.1110
Total net loss (per cent)	21.5700	11.1000

These experiments gave the first really constructive information. They showed that the powdered tile was powerfully acted upon by the peat waters, the amount of action depending upon the acidity of the peat water. In this action a semigelatinous mass was precipitated out of the solution, increasing the weight of the total solids. On treating with carbonic acid water, this gelatinous mass was removed and about as much tile dissolved as would have been the case had the tile not been previously treated with peat water.

ACTION ON NEAT CEMENT

In order to ascertain if the decaying peat had any action on "neat" cement a small quantity of the same cement as used in Table VII was mixed with water to make a stiff mortar. With this mortar small patties were made by first rolling the mortar into a ball by hand and working it thoroughly together. These balls were then flattened on glass into patties which were 2 inches across, one-half inch thick in the middle, and tapering to a thin edge. The upper surface was troweled with a spatula until the "laitance" was brought to the surface. The patties were then allowed to set in warm water for a week.

After removal from the glass the patties were placed in a jar of peat and kept moist for three months in a warm place. At the end of that time the patties were broken and the fracture examined. It was found that on the lower side where the cement had been against the glass the peat solution had penetrated to about three thirty-seconds of an inch and the surface could be easily scratched with a knife. On the upper side, however, which had been packed by hand and then troweled, there was no sign of any acid penetration, and the surface was very hard and dense.

There was no experimental work done to determine whether the resistant quality of the cement was due to the greater density of the mass, to the bringing to the surface of the "laitance," or to some other cause not indicated.

RESULTS

In addition to the five principal points brought out in the preliminary studies, five additional ones are indicated in the later work. They are:

(6) The setting of the partially decomposed tile on grinding and moistening.

(7) The gelatinous compounds of organic matter and concrete.

(8) The solubility of this compound in carbonic acid.
(9) The action of the organic compounds on neat cement.
(10) The increase in quantity of acids as decomposition proceeds.

PART IV. FIELD WORK

Before drawing a definite conclusion from the results of these laboratory investigations it was decided to make most careful field observations to ascertain if the laboratory findings were borne out by actual conditions. These observations have covered two years and during that time the subject has attracted considerable public attention. Reports have come in, notably from the muck lands of the South, which considerably broaden the scope of the investigations.

REPRESENTATIVE LOCALITIES

The field work was planned so that it should cover the greatest possible range of soil conditions. No attempt was made to get mere numbers of observations. On the other hand, an attempt was made to investigate the peats overlying dissimilar geological formations, first in Wisconsin and later in Minnesota.

LIMESTONE SOIL

In Wisconsin, eastern Dane County was taken as typical of the glaciated limestone country. This includes University Marsh, where the peat was underlain by marl. This has been described earlier in this paper. During 1920 a considerable amount of the tile in the eastern part of the marsh was relaid at a greater depth. Among these were alternate lines of Group VII. They included the lines opened up in 1919 from which the samples were taken. It was found that about half the tile were either collapsed or were not fit to be put back in the ground. This is well illustrated in Plate 3, A. This rapid final collapse, after disintegration was once well under way, later proved to be characteristic.

A large marsh of the alkaline type south of Madison, Wis., was also investigated. It lay in the bottom of a stream valley and in its natural condition would be subject to more or less periodic overflow and seepage and wash would be heavy. Water would either be standing or running in the tile the greater part of the time. A portion of this marsh was drained in 1914. The tile were examined in the spring of 1920. A pile of unused tile showed that the quality was not of the highest, as judged by present standards, but was a very good average at the time it was made. On opening up the tile lines an interesting condition was disclosed. At the outlet of the lines fresh drainage water did not enter the tiles in large quantities but found its outlet into the main ditch. The inside of the tile was covered with sediment and the concrete thereby protected. Under these conditions there was little disintegration. Farther up the lines, where water either stood or ran a larger part of the season, the cement of the tile had almost completely disappeared. On account of their fragility, there was considerable difficulty in taking out samples. The tile apparently retained their perfect shape and were functioning quite properly as long as they were not disturbed. The act of digging, however, caused their complete collapse. At the upper

end of the line, where the lower part of the tile was entirely protected by soft mineral soil, little disintegration had taken place, but the upper part was badly pitted where peat had lain against it (Pl. 2, A).

RECENT LIME DRIFT

Walworth and Ozaukee Counties were taken as representative of the heavy limestone drift area of recent formation and rich in lime. The peat swamps in this area are very narrow, have been subject to heavy wash, and are high in mineral matter. The soils are comparatively tight clays and loams and seepage is negligible. Consequently, the ground water in summer descends below the tile lines and, except for short intervals, usually remains there throughout the growing season (Pl. 2, B). Tile No. 2 came from near the mouth of a short drain where it was not subjected to standing water. No. 3, however, came from opposite the mouth of a low draw where there would be considerable seepage from the surrounding highland. The peat areas in this formation are comparatively small, and as the rate of disintegration is slow it is not expected that it will cause serious difficulty.

OLD RESIDUAL SOILS

Richland County was taken as representative of the unglaciated area, and here it was found that in the acid residual soils the tile broke down with comparative rapidity.

ACID SANDY SOILS

Wood and Juneau Counties were taken as representative of the sandstone area. These soils are for the most part very strongly acid. In this district concrete tile set in peat broke down within a year after they were laid. The sewer tile shown in Plate 4, B, was laid in clay soil high in lime. The outside gave no sign of disintegration but the inside was somewhat pitted. This area appeared to be the most destructive to concrete of any that were investigated. Throughout this whole sandy district the use of concrete in marshes appears to be only a temporary expedient. Opportunity was offered to examine the concrete culverts on the roads through the cranberry marshes of Wood County. Conditions here offer the most severe test that could be devised, for the acid waters of the cranberry marshes and reservoirs remain against the concrete throughout the season. All of the culverts and bridges examined showed signs of disintegration, the destruction having penetrated into the solid concrete. Plate 3, B, shows this very strongly.

GRANITE SOILS

Waupaca County was considered typical of the granite soils. An observation made at Wyanwega was extremely interesting, for the tile were laid not in peat, but in sand underlying muck. An area of some 53 acres was tiled in 1915. In 1917 the tile system began to give trouble. In 1918 several breakdowns occurred, owing to the complete collapse of the tile at those points. In 1919 there were over 20 breakdowns, one of which was about 100 feet long. Strange to say, in spite of its thicker wall, the 8-inch outlet main seemed to suffer the most. Plate 4, A, shows samples from this system. In no case except No. 4 did the peat come in contact with the tile. No. 3 was taken from a tile line on a flat piece of high ground. There was no peat on this line.

MINNESOTA CONDITIONS

In the late fall of 1920, the writer removed to Minnesota. This State does not have drained peat bogs or swamps on the wide range of soils that occur in Winconsin. Practically all of the Minnesota peats that have been drained are of the "high lime" type. A large proportion of them are in sloughs and depressions of the low ground of the northwestern glacial drift whose soil is composed almost entirely of ground-up shale and limestone. The peats themselves are built up mostly of plants of a high botanical order.

The low lime peats of Minnesota lie largely to the north and northeast overlying the more acid, northeastern drift and the rock outcrops of that part of the State. They are derived mostly from the remains of plants of a low order, in which the mosses predominate. Low lime peats in Minnesota have not yet proved their economic importance. Underdrainage of any soils is not far advanced in the northeastern part of the State and the farming of peat can be said to have not yet begun.

GRAND RAPIDS STATION

LOW LIME PEAT

Opportunity was offered to investigate only one tract in Minnesota where a low lime bog had been drained for a number of years. In fact, it is the only one known in the State where concrete tile has been used. This was on the State experimental farm at Grand Rapids, Minn. The tract was tiled in 1910 under the direction of the State experiment station at St. Paul, Minn., Prof. J. T. Stewart being directly in charge of the work. The tile lines were laid an average of about 3½ to 4 feet deep. Part of the area tiled was cultivated experimentally. The rest was left in its natural condition. In 1918 the system showed signs that it was not functioning properly. Water did not drain away after storms as it should. In 1918 almost the entire system was taken up and relaid. It was found that about one-fourth of the tile had completely collapsed or were not fit to put back in the ground. The design of the system was somewhat altered. The 75 per cent of the tile that were in fair condition were used a second time and the balance was replaced with clay tile.

Plate 5, A, B, and C, shows different views of one of the better tile that was stock piled and kept for use. Disintegration was not serious on the outside at top and bottom, but was considerable on the sides. The top inside shows no signs of disintegration, but the bottom inside is very badly eaten.

In June, 1921, the lines were examined. Plate 6, A, shows the specimens taken. No. 1 was from the cultivated area on the central line which was relaid. The specimen came from 50 feet south of the fence. No. 2 was taken from the same line 50 feet north of the fence in uncultivated peat. It is interesting to note the greater disintegration of the tile in the raw peat. The peat at the Grand Rapids station is very fibrous and was cut out by the tilers in large pieces. When these were thrown back into the trench they frequently formed an arch over parts of the tile without touching it. The results of this are shown in No. 2, Plate 6, A, and the actual conditions in the ground in Plate 5, D. On all of the body of the marsh the ground water would drop below the tile lines throughout the greater part of the season. No. 3, Plate 6, A, was taken from mineral soil in a part of a line that was not relaid. This was

a seepage line that ran along the western edge of the bog but, at the place where the sample was taken, cut across a point of high ground about 200 feet wide on which there was no peat.

Crumbs were broken off by hand from the rotted portion of all of these tile, powdered, shaken up with distilled water for one minute and tested for free alkali. All gave a violent alkaline reaction.

The strength and absorption of these tile were tested in the drainage laboratory of the Minnesota Experiment Station by D. G. Miller, senior drainage engineer of the United States Department of Agriculture, and J. A. Wise of the Minnesota Experiment Station. The difference in porosity between the decayed tile and that which was not decayed is not strongly brought out. The fact is indicated that the tile were of high grade for the time they were made.

TABLE XV.—*Results of physical tests of concreate tile in peat (11 years) at Grand Rapids, Minn.*

Item.	No. 1.	No. 2.	No. 3.
Internal diameter (in.)	5	5	6
Weight (lbs.)	8. 72	8. 81	12. 02
Breaking load pounds (per linear ft.)	819	783	851
Absorption, bone dry and boiling method (per cent)	.....	.....	.....
Top in mold, lower side in marsh	11. 8	13. 6	11. 7
Center piece, upper side in marsh	12. 0	.....	10. 2
Center piece, side in marsh	.....	13. 7	.....
Bottom in mold, upper side in marsh	11. 3	11. 9	.....
Bottom in mold, lower side in marsh	.....	.....	10. 5

COON CREEK HIGH LIME PEAT

Early in 1921 a movement was started to show that concrete tile would not disintegrate in peats carrying a high percentage of lime. This claim was supported by most eminent authorities and there was no published work to contradict it. As the high lime peats include all the peat areas of Minnesota that are yet of economic importance and the greater part of those of southern Wisconsin, the point raised was paramount. For the investigators to be able to limit the destruction of concrete to the low-lime peats would be of immense benefit to the States affected, for it would reduce the problem to the proportions of an academic study. It would, however, necessitate a classification of the peat areas before drainage. The results of the observations on high-lime peat are therefore given in some detail.

A peat area was selected that was assumed to offer ideal conditions for the preservation of the tile, i. e., the Coon Creek experimental tract. Here a peat area 3 to 6 feet deep is underlain in its deeper portion with marl of unknown depth and extent but sounded to a thickness of 17 feet.

The tract was selected by Dr. F. J. Alway, chief of the soils division of the Minnesota Agricultural Experiment Station, for experimental work in the agricultural utilization of high lime peats and is maintained for that purpose. On the south, the tract is bounded by low hills of wind-blown sand, derived from the limestone drift of the northwest glaciation. This sand extends out underneath the peat some 300 to 400 feet, where it drops off quite sharply, marl occupying the depression between the sand and the peat above. The part under cultivation extends a little beyond the shoulder where the sand drops away, and the outer lines of tile (laterals

1 and 2 on the map, 1 to the westward and 2 to the eastward of the main) have a few inches of marl under them below the peat.

There is very heavy seepage from the sand hills down through the sand underlying the peat. Natural escape of the seepage water at the main channel of Coon Creek is blocked by the comparatively impermeable marl. The main outlet drain of the tract cuts across the marsh and supplies the necessary outlet. The laterals at the time they were laid were from 3½ to 4 feet deep, and are now 3 to 3½ feet below the surface of the peat. There is from 1 to 1½ feet of peat between the bottom of laterals 1 and 2 and the sand. The main outlet, however, since it was first dug has always been about a foot below the outlets of the laterals. There has been a tendency, therefore, in times of little flow for the seepage water to escape directly from the sand into the main outlet without passing upward into the laterals. This condition would be accentuated both at the lower end of the laterals near the main and at the upper end of the laterals where their grade carries them above the almost flat ground water table. Lateral 1 carries heavy seepage from a bay indenting the high land, and the tendency for the ends of the lateral to get above the ground water level would be partially neutralized. In lateral 2, however, the tendency would be most marked at all low water stages.

The tile system was laid out and installed in 1918 under the direction of Mr. H. B. Roe, drainage engineer of the experiment station. Alternate lines were of clay and concrete. When the concrete tile arrived they were freshly cured and did not meet the strength requirements. As they also appeared to be quite uniformly porous the entire lot was condemned by Mr. Roe. Another test of the tile was made 13 days after the first, which indicated a much greater strength. Under the circumstances it was decided by Doctor Alway that it would be better to use the tile than lose a season. The tile were therefore installed.

TABLE XVI.—*Tests of Coon Creek tile Oct. 2, 1918, one week after delivery (5 and 6 inch tile tested)*

Test No.	Wet weight.	3-point breaking load.	Calculated breaking load.
	Lbs.	*Lbs.*	*Lbs.*
1	9¾	375	562
2	10	375	562
3	10¼	413	620
4	10	325	488
5	10⅛	425	638
Average	10. 025	382. 6	574

TABLE XVII.—*Tests of Coon Creek tile Oct. 15, 1918, three weeks after delivery (5-inch tile tested)*

Test No.	Dry weight.	3-point breaking load.	Calculated breaking load.
	Lbs.	*Lbs.*	*Lbs.*
1	8¾	538	807
2	8⅛	675	1, 013
Average	8. 56	606. 5	910

From Tables XVI and XVII it would appear that the average cold absorption of the air tile was approximately 1.465 pounds, or 17.1 per cent, and that Mr. Roe's condemnation of the tile was well founded.

In June, 1921, an inspection of the tile was arranged for, to take place, on August 1, Doctor Alway acting as intermediary. There were present the local manager of a cement association, the director of the publicity department of the same cement association, the engineer for a Minnesota concrete pipe and tile association, Dr. F. J. Alway, of the soils department of the agricultural engineering branch of the Minnesota Experiment Station, and the writer.

Altogether, five pits were opened, the location of the first three being chosen by the representative of the cement association and the location of the last two being chosen by the writer. The first three pits were all opened on lateral 2 at 265, 450, and 600 feet from the main. This lateral, as previously described, is underlain by marl, at a depth of about 1 foot below the grade of the tile. Two tiles were taken from each pit and were numbered in duplicate 1A, 1B, and 1C. At the writer's suggestion branch a of lateral 1 was opened 20 feet from its outlet and again at 735 feet from its outlet. The first of these two pits was underlain by marl. The second was in uncultivated peat and had no marl below it. Two samples were taken from each pit and numbered in duplicate 2A and 2B. The samples were set up in order on the running board of one of the cars and photographed by members of the party. One set was then chosen by the publicity director of the cement association and the other taken by the writer. The upper and lower sides of the samples taken by Elliott are shown in Plates 7, A and B. It will be noted that the tile which remained above the water table for long periods of time are very little attacked, while the tile which kept moist without much flow even though close to the marl is more disintegrated than those which carried a heavy flow of high ground water. Of the two from branch a, the tile taken from above the sand is more disintegrated than the one from above the marl. Samples of water were taken from the pits by the publicity man. On digging holes to the grade of the tile for the collection of water no water appeared. The holes were then deepened still more. At hole 1 B, the shovel handle was thrust down through the marl to the sand underneath. The water then rose in the hole. At pit 2 B, the hole was deepened almost to the underlying sand, permitting the water to collect. What was done with these samples is not known to the writer, but they can not be taken as representative of the water in the peat. They would be representative of the ground water in the sand subsoil, probably contaminated by the marl and peat.[4]

The samples of the tile taken by Elliott were tested on October 25 in the drainage laboratory of the experiment station. Crumbs were broken by hand from 1B, 2A, and 2B. All showed a strong alkaline reaction. The results of the physical tests are given in Table XVIII.

[4] Since the above was written the 1922 report of the American Society for Testing Materials has come to hand. It is believed that the samples tested by Dr. Witt and referred to in paragraph 3, p. 262 of that report, are the samples just mentioned.

TABLE XVIII.—*Results of physical tests on samples* [1] *2¾ years in peat taken from drains at Coon Creek Aug. 1, 1921 (5-inch tile tested)*

Physical tests.	Sample. 1A.	Sample. 1B.	Sample. 1C.	Sample. 2A.	Sample. 2B.
Weight after 3 months drying (pounds).	9. 70	9. 02	9. 19	9. 27	9. 53
Breaking load (pounds)	826	804	1007	810	1016
Absorption, bone dry and boiling method;					
Top piece in mold	12. 9	15. 6	13. 7	13. 8	13. 6
Center piece in mold	14. 3	17. 9	15. 1	16. 2	15. 4
Bottom piece in mold	14. 1	13. 1	13. 3	17. 4	15. 8
Average	13. 8	15. 5	14. 0	15. 8	14. 9

[1] A considerable number of tile had been left over when the job was finished, and had been stock piled on high ground at the edge of the marsh. Of these, 10 were taken as a sample, 5 being given to the soils department and 5 tested on October 25 in the drainage laboratory.

TABLE XIX.—*Results of physical tests on concrete tile from stock pile at Coon Creek (5-inch tile tested, age 3 years)*

Physical tests.	Sample 1-6.	Sample 1-7.	Sample 1-8.	Sample 1-9.	Sample 1-10.
Weight after 3 months drying (pounds.)	10. 27	9. 30	10. 25	9. 61	10. 00
Breaking load (pounds)	1152	983	1196	830	1265
Absorption:					
Top piece in mold	12. 2	13. 3	11. 8	15. 1	13. 4
Center piece in mold	12. 2	15. 6	13. 1	14. 1	16. 3
Bottom piece in mold	13. 2	14. 2	13. 0	14. 5	14. 3
Average	12. 5	14. 4	12. 6	14. 6	14. 7

A comparison of the figures in these tests discloses some interesting facts that are tabulated in Table XX.

TABLE XX.—*Comparison of physical tests on Coon Creek tile at different ages and under different conditions*

Physical tests.	1 week after delivery.	3 weeks after delivery.	3 years old in stock pile.	2¾ years old in peat.
Weight, air dry average	.....	8. 56	9. 89	9. 34
Wet weight	10. 025	.....	.....	.....
Breaking load, dry	.....	910	.....	.....
Breaking load, wet	574	.....	1085	893
Absorption, cold, per cent (estimated)	17. 1	.....	.....	.....
Absorption, boiling	.....	.....	13. 8	14. 8
Absorption, top piece in mold	.....	.....	13. 2	13. 9
Absorption, center piece in mold	.....	.....	14. 3	15. 8
Absorption, bottom piece in mold	.....	.....	13. 8	14. 7

TABLE XXI.[1]—*Comparison of tile in peat with tile from stock pile at Coon Creek, tested Oct. 25, 1921*

Item.	Per cent.
Loss in weight	5.5
Loss in strength	17.8
Increase in porosity:	
Ends	5.2
Middle	10.4

[1] Summary of Table XIX

PEAT IN LAKE PRAIRIE DISTRICT

On September 19, 1921, a concrete tile line was examined on the NW. ¼ and SW. ¼, sec. 29, township of Lake Prairie, about 10 miles northwest of St. Peter, Minn. In 1919, an 8-inch tile had been laid a short distance into a peat pocket about 1,200 feet long. The line was not completed. After eight months in the ground the tile was taken up and found to be very badly disintegrated on the bottom, as shown in Plate 6, B. New tile was laid in the fall of 1920 and the main completed. At the time of the examination it also showed signs of serious disintegration. No samples of the new tile were taken. Tests of the old tile showed physical conditions as summarized in Table XXII.

Table XXII.—*Absorption tests, bone-dry and boiling method, of concrete tile in peat 8 months, and on bank 1 year, near St. Peter, Minn.*

Sample taken.	No. 1.	No. 2.
Top piece in mold	13.0	25.3
Center piece in mold	16.6	19.3
Bottom piece in mold	14.6	14.6
Average	14.7	19.8

All of the fragments of tile No. 1 were from the upper side. The upper and center fragments of tile No. 2 were from the partially disintegrated portion. The tile were apparently of about the same character originally, a rather low grade without sufficient coarse aggregate.

RESULTS

In addition to the 10 points brought out in the laboratory, the field studies indicate the following:

(11) Concrete tile, as at present made, break down in all peat soils, no matter what the underlying mineral soil may be.

(12) A high percentage of lime, even the presence of marl, is no guaranty of immunity.

(13) A high percentage of lime delays but does not stop the process of disintegration.

(14) An acid subsoil aids in the disintegration.

(15) The more porous the tile the more rapid the disintegration.

(16) The presence of water is necessary for disintegration to take place.

(17) It is not necessary for the tile to be actually in the peat for disintegration to take place, but merely that the peat waters shall have free access to it.

(18) The violent alkalinity of the tile, continuing even to the time of complete disintegration.

(19) The destruction of solid concrete if the acid waters lie against it continuously.

PART V. DISCUSSION AND CONCLUSIONS

The mechanical adaptability of such a material as concrete to the manufacture of drain tile and the aid which it can give to drainage work is very great. Its permanence in ordinary soils seems to be all that can be desired. That, however, is not a part of the discussion of this paper. It is with the suitability of concrete for peat soils or soils high in organic matter with which this paper deals.

From the facts brought out in the investigation it would seem that there are some things which should be remedied before concrete tile, as now made, can be said to be suitable for use in soils high in organic matter. The first of these difficulties is the presence of free alkali. The observations of the past year seem to indicate that this is a characteristic of all concrete tile, retained even to the time of complete collapse. If it is true that free alkalinity is an inseparable characteristic of concrete as now made, and if water is present as a conveying medium, then the ultimate destruction of the tile in the presence of organic acid seems inevitable. The free alkali and the free acid are incompatible and must react against one another. This might not be serious if the products of the reaction were insoluble in water. The investigation has shown that they are highly gelatinous and are very readily soluble in water carrying carbonic acid.

That carbonic acid is absorbed in large quantities by the concrete is indicated by the tests with the cement patties. It may also have had considerable to do with the increase in weight and density of the tile which lay in the stock pile at Coon Creek.

Destruction of the concrete by water carrying carbonic acid must eventually take place exactly as the lime is leached from the surface of any soil by the formation of the double carbonates of calcium, but this process probably would be extremely slow and would not be of economic interest to the engineer. It is the rate of decomposition that is the controlling factor.

DISINTEGRATION IN LOW-LIME PEATS

On this rate of decomposition, the character of the surrounding mineral soil, the porosity of the tile and the character of the ground water flow, seem to be the controlling factors. In strongly acid soils, with the peat wet throughout the season, ordinary tile appear to break down after one year. At Grand Rapids, Minn., the peat is highly acid but the tile were laid shallow and the ground water, except for short intervals, kept well below them through the greater part of the season. Some of the tile were in fair condition at the end of 11 years. At Weyauwega, Wis., in acid soil in the presence of abundant moisture, the tile were not placed directly in peat but in the sand below it. The system began to give trouble after two years and was very bad in three. In Wood and Juneau Counties, Wis., in acid peat above acid subsoil poor tile break down in a year.

DISINTEGRATION IN HIGH-LIME PEATS

In the high-lime peats the situation is much more complex. Water still is a controlling factor. At St. Peter, Minn., a rather poor grade of tile broke down in a season. This was in a so called running slough in Prairie Country which would therefore be high in lime, but the bottoms of the tile were wet throughout the season. At Coon Creek, during the two and one-half seasons they were in the ground, the tile disintegrated most rapidly where there was a gentle flow or soakage of water regardless of the presence of lime in the form of marl. Where the flow of ground water was stronger, even though marl was not present, disintegration was not so great. Where the tile were well above the ground water level throughout the greater part of the season, disintegration amounted to very little.

On University Marsh the conditions were very unusual. The marsh surface was below the level of Lake Mendota. There is, in addition, heavy seepage from the surrounding hills. This seepage coming through the marl bed was so strong that the peat was prevented from attacking the bottoms of the tile. This is the reverse of what is commonly found. The tops of the tile were, however, above the seepage water and were destroyed after six years. This is the more remarkable in the light of the fact that during the winter the seepage was sufficiently strong to turn the deeper peat strongly alkaline and almost neutralize it to the surface.

In Ozaukee County the least proportional disintegration was found. The marsh in this case was narrow and the main ditch comparatively deep. The tile would be above the water level throughout the greater part of the season. As was to be expected, the greatest disintegration was found where the tile were kept continuously moist. In none of the three observations made in this county was there any serious disintegration after four years.

PRODUCTION OF ORGANIC ACID

One of the most interesting facts brought out by the investigation was the extremely rapid production of organic acids where moist peat was kept at a warm temperature. In the laboratory culture of peats from University Marsh, both the peat from the surface, which was very faintly acid, and the peat from 5 feet deep, which was strongly alkaline, in 10 days became strongly acid. In another 10 days the surface peat contained 5 times as much acid as it did at the end of the first 10 days. The deep peat in the second 10 days not only increased its acidity to 7 times what it was at the end of the first 10 days but actually outstripped the shallow peat. The northern peat which was but faintly acid in the beginning became violently acid at the end of 10 days.

The same thing was done during this past winter with peat from Coon Creek. The peat culture in distilled water required a week to overcome its original alkalinity, after which time the increase in acid was rapid.

It is not assumed that exactly the same sort of accumulation of acid will occur in nature though the process of production may be identical. What will occur will be the production on an enormous scale of the products of decay. Much of these will naturally escape and be carried away by ground water. In the cooler months, particularly in the winter, the escape of the products of decay will probably more than keep pace with

their production. But in the summer months when run-off is light and decay rapid, the products of decay must accumulate to a very great degree. If there is any run-off through the tile lines, these products of decay will find their way to the tiles along with the drain water. The percentage of concentration of the acid in the drain water may be very low, but the actual amount passing during a season would be enormous. With the drain water also carrying carbonic acid, the complex compounds formed with the cement would be immediately carried away, presenting a fresh face to the action of the organic acids.

Though this process is evidently very similar to the leaching of lime from surface soil, a little thought will show that they are not exactly analogous. The lime in the soil is present in a comparatively inert form. It has been demonstrated that the concrete of the tile is chemically active even to the very end of the tile. It is possible that the ordinary soil is better able to retain the complex lime-organic compounds than is the peat. It has been shown that tile near the surface of a well-drained peat are not greatly affected. It is possible that the greatest injury is done by organic compounds that are produced in quantity only where the conditions are suitable. It is possible that these conditions may not exist in a mineral soil. This leads us to the statement that the deductions from this investigation can not be stretched to include the use of concrete tile in mineral soils whether acid or alkaline.

ECONOMIC FACTORS

Though, under certain conditions, the life of a concrete tile in peat soil may be very short, under certain other conditions it may continue a long time. In general, it may be said that the average life of concrete tile, as they have been made, is about six years. The tile may hold on for a considerable time during which the violent alkalinity is being neutralized, after which the final collapse is rapid. In peat soils the collapse of the tile may not be as serious as it would be in a mineral soil, nor may the collapse at once become apparent. If the drain is not closed by the tramping of stock or by farming operations, the underground channel may remain open for years, functioning nearly as well as the original drain.

It will probably be said that the quality and density of concrete tile is improving rapidly and that the tile at Coon Creek, for instance, were not good tile and were condemned before they went into the ground. Even though they were not good tile, however, they were no worse than many hundreds of miles of tile that have been used. They were shipped from the factory while still "green," and the first test was made when they were only partly cured. That is not the point, however. The point is that during the two years in the ground the tile lost in every quality that fits them for the work for which they are intended.

If the average expectation of the life of the tile were 40 or 50 years or upward, there would probably be no question as to the advisability of using concrete tile, but with an expectation of only 6 or 10 years it does not seem that, as now made, their use in peat is sound economics. It would seem to be a question whether or not they would pay for the investment and give a sufficient profit during that time to reimburse the land owners for the trouble and business hazard involved. No doubt improvements in the quality of the tile which are now being generally made will greatly increase the life of the tile, but those improvements are with few

exceptions leading to the improvement of one quality only, and that is density.

But density alone is not sufficient. In the progress of the field work, the greatest possible range of soils was investigated. It is significant that in no place where concrete tile were in peat for two or more years were the tile free from some percentage of disintegration. We can not assume that all of these tile, covering some 30 odd observations in two States, were below the average in quality.

IMPROVEMENT NECESSARY

It would seem that the first requisite for making the concrete permanent in a soil high in organic acids is the elimination of the free alkali. It is generally understood that an excess of lime is added to the materials of which cement is made in order to give it setting qualities and plasticity. If these qualities are necessary for a general purpose cement, it is possible that a special cement might be made for use in drain tile in peat soils which would not have the objectionable features of the standard product.

The second suggested improvement would probably be covered by the first, but if the first were not put into effect it would seem that a very distinct improvement could be effected by finer grinding. This would permit of more complete hydration at the time of setting. The "setting" of the old tile when it was reground would seem to indicate that perhaps the original particles of cement were too large for the process of hydration to be complete even after five years.

The third suggested improvement in the manufacture of concrete tile for use in peat soils is the addition of some substance which would either render the constituents of the cement chemically inert or would so coat the particles of the tile that the entrance of water would be prevented. If this could be done the tile would last as long as the coating remained intact. If such a material were used it must of necessity be of such a character that it itself would not decay.

The fourth method of improvement is the one that is at present being used. It involves greater care in the mechanics of manufacture of the tile, and includes washing, grading, and elimination of soft materials from the aggregate, better mixing and blending and better packing and curing. The result is a stronger, denser tile that is greatly superior to the tile made by a more careless process. Its life in any soil, but particularly in soils which carried inimical solutions, would be very greatly lengthened. It is possible that this method combined with the addition of a preservative substance will produce the desired results. Very great improvement has already been made along that line, and the utmost thought and care should be expended in an effort to produce a concrete that is unquestionably permanent.

LITERATURE CITED

(1) ALWAY, F. J.
1922. DISINTEGRATION OF CEMENT TILE IN PEAT. *In* Jour. Amer. Peat Soc., v. 15, no. 3, p. 15–25. References, p. 25.

(2) BATES, P. H., PHILLIPS, A. J., and WIG, R. J.
1913. ACTION OF THE SALTS IN ALKALI WATER AND SEA WATER ON CEMENTS. U. S. Bur. Standards, Tech. Paper 12, [1912], 157 p., 60 fig. Bibliography, p. 103–105.

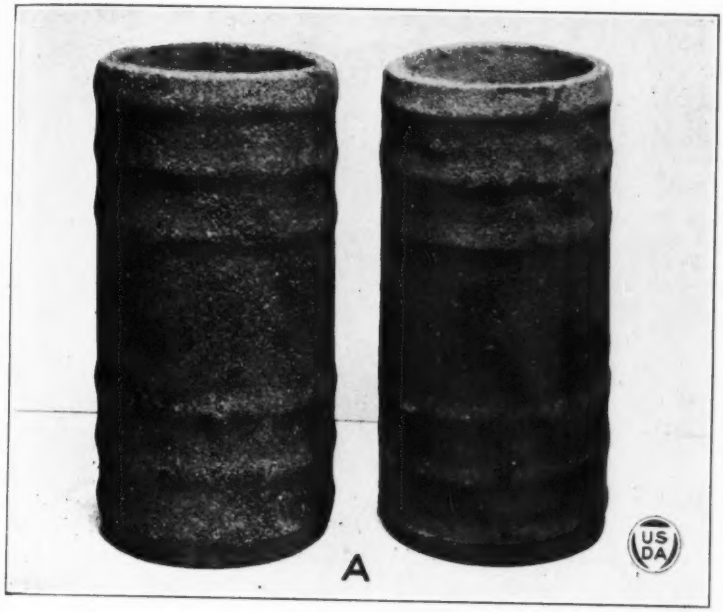
(3) BERSCH, Wilhelm.
1909. HANDBUCH DER MOORKULTUR. xii, 288 p., 41 fig., 8 pl. Leipzig.

(4) ELLIOTT, G. R. B.
1921. DURABILITY OF DRAIN TILE. *In* Farm, Stock and Home, v. 37, p. 226–227, 262.
(5) ——— JONES, E. R., and ZEASMAN, O. R.
1921. PUMP DRAINAGE OF THE UNIVERSITY OF WISCONSIN MARSH. Wis. Agr. Exp. Sta. Research Bul. 50, 32 p., 15 fig.
(6) HALL, A. D., and MORISON, C. G. T.
1907. THE FLOCCULATION OF TURBID LIQUIDS BY SALTS. *In* Jour. Agr. Sci., v. 22, p. 244–256, pl. 4.
(7) HEADDEN, William P.
1908. DESTRUCTION OF CONCRETE BY ALKALI. Colo. Agr. Exp. Sta. Bul. 132, 8 p.
(8) MILLER, D. G.
1922. EFFECT OF ALKALI ON CONCRETE DRAIN TILE AND GENERAL CONDITIONS OF ALKALINITY IN SOUTHWESTERN MINNESOTA. *In* Bul. Minn. Federation Architect. and Engin. Soc., v. 6, No. 8 (1921), p. 13–23, 5 fig.
(9) ———
1921. REPORT OF CONCRETE-ALKALI INVESTIGATIONS IN MINNESOTA IN 1919–1920, BY THE COMMISSIONER OF DRAINAGE AND WATERS OF MINNESOTA. 74 p., 2 fig.
(10) STEIK, Karl.
1917. THE EFFECT OF ALKALI UPON PORTLAND CEMENT. Wyo. Agr. Exp. Sta. Bul. 113, 122 p., 9 fig.
(11) ———
1919. THE EFFECT OF ALKALI UPON PORTLAND CEMENT—II. Wyo. Agr. Exp. Sta. Bul. 122, 38 p., 22 fig.
(12) STEWART, John T.
1922. DURABILITY OF CONCRETE TILE IN PEAT. *In* Jour. Amer. Peat Soc., v. 15, no. 3, p. 26–32.
(13) TACKE, Bruno.
1910. UEBER DAS VERHALTEN VON BETEN IN MOORBODEN. *In* Mitt. Ver. Förd. Moorkultur, Bd. 28, p. 234–240.
(14) TANNATT, E. Tappan, and BURKE, Edmund.
1908. THE EFFECT OF ALKALI ON PORTLAND CEMENT. Mont. Agr. Exp. Sta. Bul. 69, 120 p., 9 pl.
(15) VOGLER, Charles A.
1909. GRUNDLEHREN DER KULTURTECHNIK. Aufl. 4. Bd. 1, Teil 1–2. Berlin.
(16) WIG, R. J., and WILLIAMS, G. M.
1915. INVESTIGATION OF THE DURABILITY OF CEMENT DRAIN TILE IN ALKALI SOILS. U. S. Bur. Standards, Tech. Paper 44, 56 p., 50 fig.
(17) ——— ——— and FINN, A. N.
1917. DURABILITY OF CEMENT DRAIN TILE AND CONCRETE IN ALKALI SOILS. U. S. Bur. Standards, Tech. Paper 95, 94 p., 61 fig.
(18) ——— ——— and GATES, E. R.
1916. STRENGTH AND OTHER PROPERTIES OF CONCRETES AS AFFECTED BY MATERIALS AND METHODS OF PREPARATION. U. S. Bur. Standards, Tech. Paper 58, 172 p., 44 fig.
(19) WILLIAMS, G. M.
1922. DURABILITY OF CEMENT DRAIN TILE AND CONCRETE IN ALKALI SOILS: THIRD PROGRESS REPORT (1919–20). U. S. Bur. Standards, Tech. Paper 214, p. 463–494, 6 fig.
(20) WINTER, O. B.
1917. DURABILITY OF CONCRETE DRAIN TILE—II. Mich. Agr. Exp. Sta. Spec. Bul. 82, 12 p.
(21) ——— and MUSSELMAN, H. H.
1915. DURABILITY OF CONCRETE DRAIN TILE. Mich. Agr. Exp. Sta. Spec. Bul. 75, 13 p., 4 fig.

PLATE 1

A.—Concrete tile on left laid in deep peat on University Marsh in 1918. Taken up in 1919. The tile to the right is new.

B.—Concrete tile at left laid in peat 3½ feet deep underlain by marl in University Marsh in 1914. Taken up in 1919. The tile to the right is new.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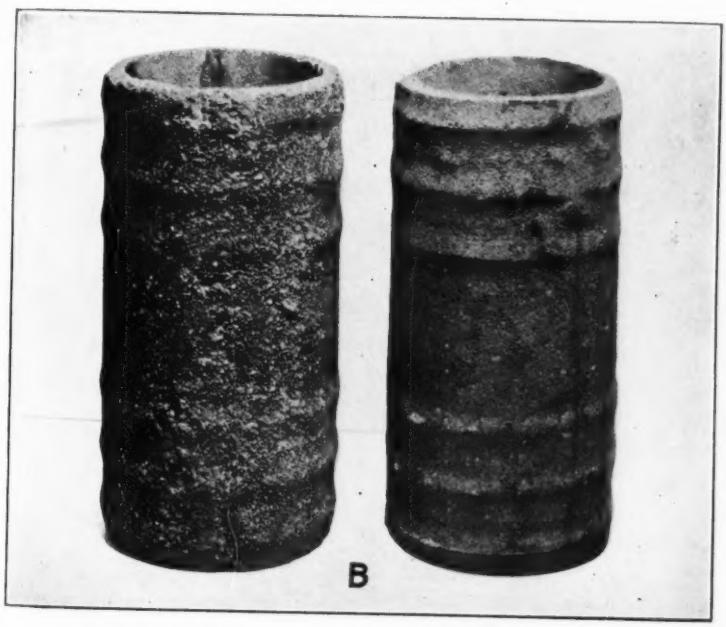
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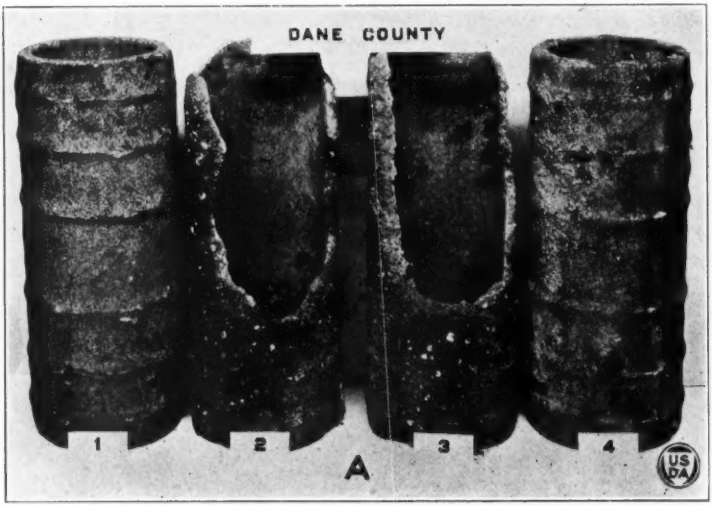
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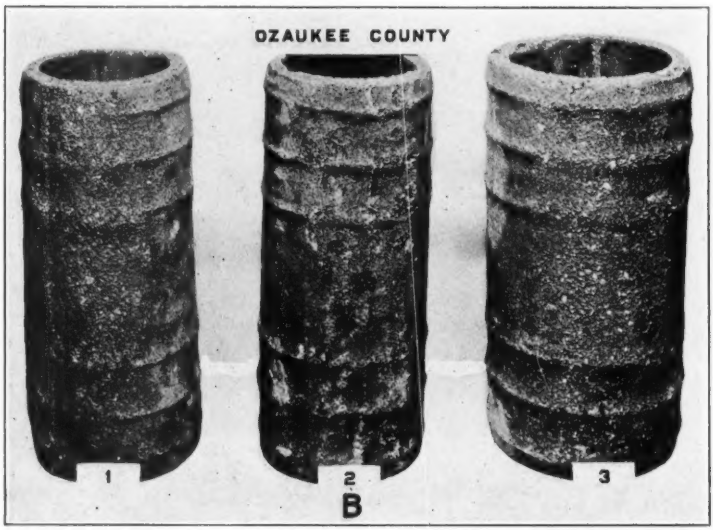
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PLATE 2

A.—Concrete tile laid near Madison, Wis., in 1914; taken up in 1920. No. 1 has not been in the ground. Nos. 2 and 3 were laid 3½ feet deep in peat. No. 4 was in silt loam overlain by 2 feet of peat.

B.—Concrete tile laid in recent soil high in lime in 1916; taken up in 1920. No. 1 was in peat carrying a high percentage of alluvial matter and getting high ground wash. No. 2 was at the outlet of a drain in 4 feet of peat. No. 3 was in 4½ feet of peat overlying sand.

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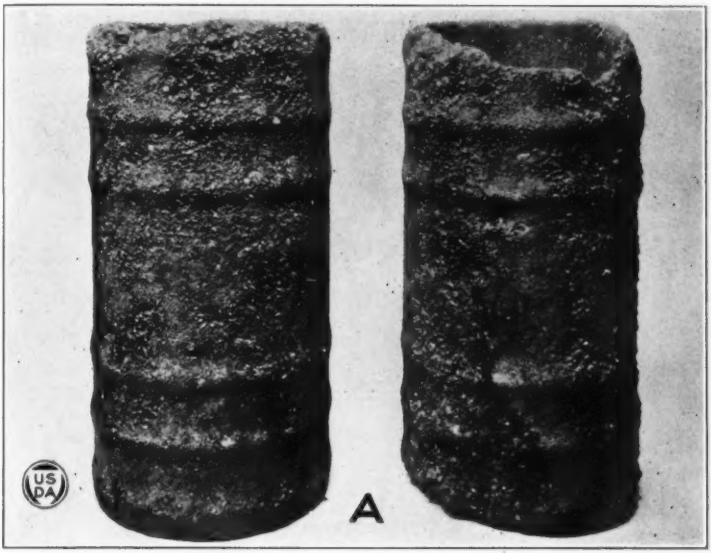
PLATE 3

A.—Tile from University Marsh. From same line as in Plate 1B, but taken up in fall of 1920. Note progressive disintegration in Plates 1, A, 1, B, and 3, A.

B.—Concrete culvert in Gaynor Road, Grand Rapids, Wis. Built about 1910. Photographed September, 1920. Acid water from the cranberry marshes stands against the concrete at all times.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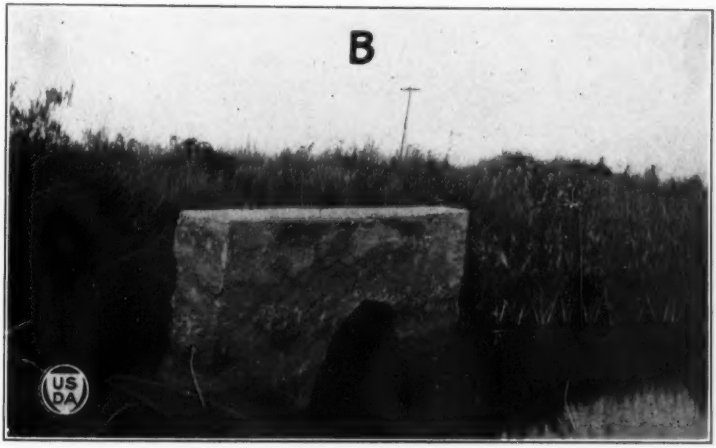
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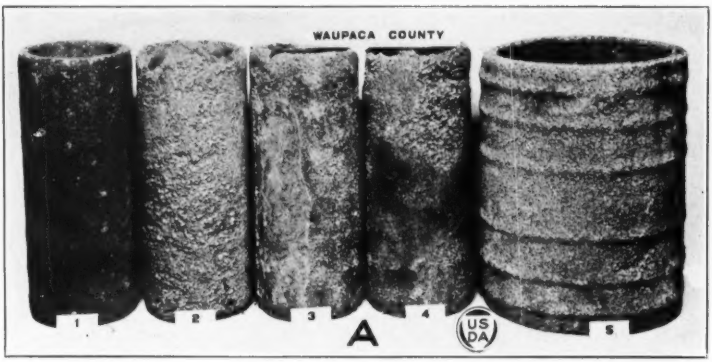
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PLATE 4

A.—Concrete tile laid in Central Plain of Wisconsin in 1915, taken up in 1919. No. 1 lay on the ground. No. 2 was in sand below 8 inches of black muck. No. 3 was in silt loam with sand at 3 feet 6 inches. No. 4 was in bowlder clay underlying 12 inches of black muck. No. 5 was in sand below 8 inches of black muck.

B.—Concrete tile laid in a sewer in Milwaukee about 1885. Taken up in 1919.

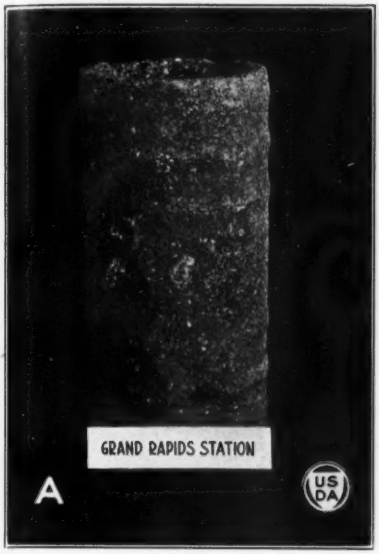
PLATE 5

A.—Tile from Grand Rapids Experimental Farm. Laid 1910. Taken up 1918. Laid in pile until 1921.

B.—Same as Plate 5, A, showing tile disintegrated on inside at bottom.

C.—Similar to preceding, showing disintegration at water line.

D.—Grand Rapids station, showing sample No. 2 in the ground with the peat arched above it.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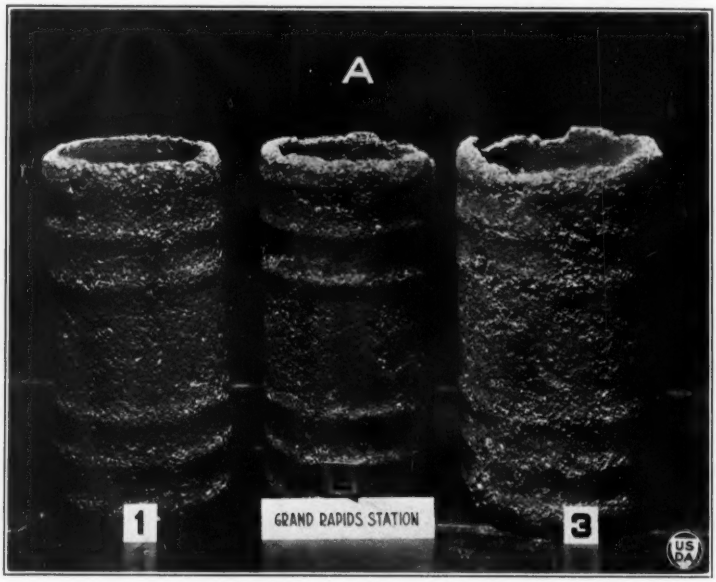
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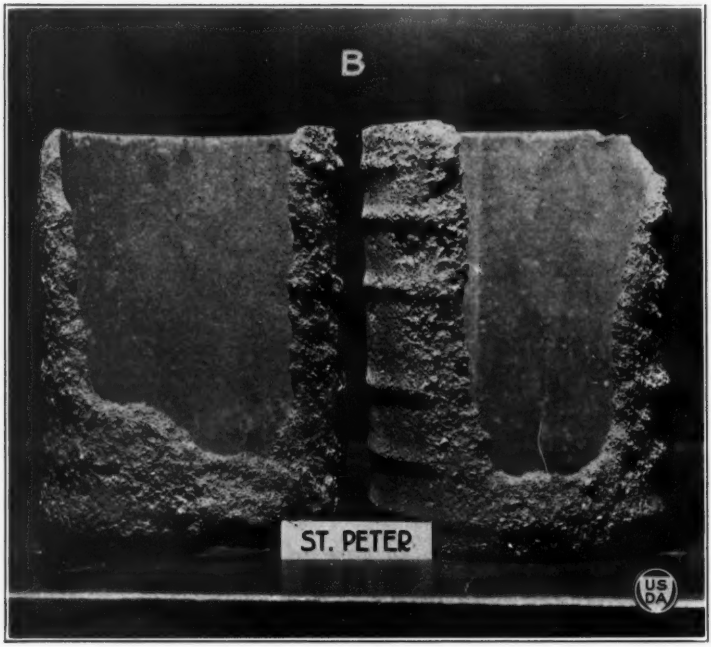
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PLATE 6

A.—Some of same lot laid 1910. Taken up 1918. About one-quarter of tile discarded; remainder relaid. Samples taken up 1921. No. 1, bottom of tile in deep peat. No. 2, top of tile in deep peat. No. 3 taken from 3½ feet deep in mineral soil. Seepage line, but carried peat waters. This portion of line had not been relaid since 1910.

B.—Eight-inch tile from line in peat northwest of St. Peter. Laid in 1919. Taken up after eight months. Second set, relaid in 1920, showed signs of heavy disintegration in September, 1921.

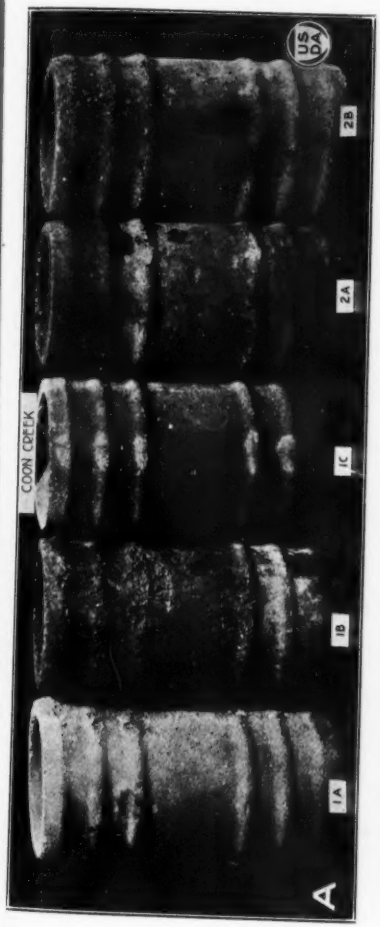
PLATE 7

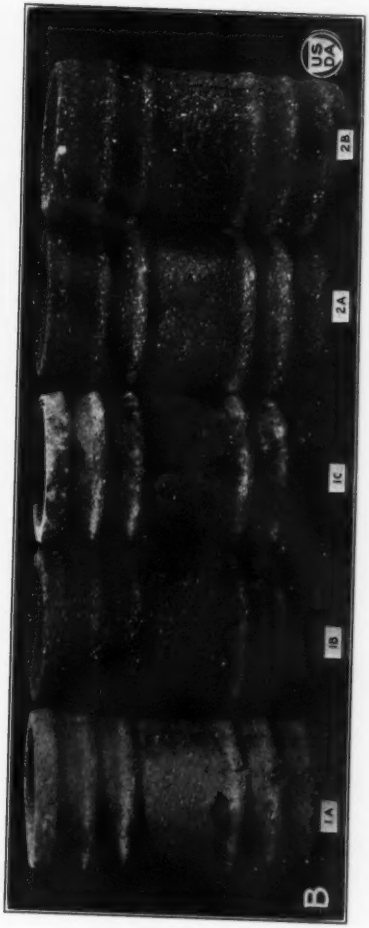
A.—Upper side of set of tile from Coon Creek, taken by Elliott for testing; 1A, 1B, and 1C taken from pits on lateral 2, peat underlain by marl; 2A and 2B from pits on branch a of lateral 1, 2A peat underlain by marl, 2B peat underlain by sand.

B.—Bottoms of same set as shown in A.

Effect of Decomposition on Concrete Tile

PLATE 7





Journal of Agricultural Research

Washington, D. C.

INJURY TO FOLIAGE BY ARSENICAL SPRAY MIXTURES[1]

By D. B. SWINGLE, *Botanist*, H. E. MORRIS, *Assistant Botanist*, and EDMUND BURKE, *Chemist, Montana Agricultural Experiment Station*

INTRODUCTION

Since the first trials of Paris green and of arsenic trioxid for the control of the potato beetle half a century ago there has been a constant increase in the use of arsenical compounds for controlling the ravages of certain species of insects on economic plants.

It is a notable fact that of the many poisonous substances known to physiological chemistry none has been found so well suited to the purpose of poisoning insects that obtain their food by gnawing away portions of the fruit and foliage as certain arsenical compounds. As the control of such insects is a very important field in the science of entomology, much practical and scientific interest centers around this group of compounds. This interest makes imperative the obtaining of more information along certain lines; for it is agreed that an arsenical compound to be a satisfactory insecticide for application to foliage shall approach perfection in these respects: (1) It must promptly kill a large proportion of the insects; (2) it must be relatively inexpensive; (3) it must not seriously injure the plants to which it is applied under the conditions obtaining. Unfortunately, no compound has yet come to notice that perfectly satisfies these requirements, though several do so sufficiently well to be extensively used. It is with the third requirement that this investigation deals, although the others are constantly kept in mind.

The problem of arsenical injury to fruit trees and garden crops as a result of spraying is a troublesome one. Some of the compounds first tried have been abandoned or greatly restricted because of the injury produced and new ones have been proposed to take their places; and these in turn may yet give way to others.

It has long been evident that there are factors influencing arsenical injury that the horticulturist does not understand and others that he is powerless to control. Considerable work has been done to show the nature and relative importance of these factors. All of this work has been fragmentary and most of it has been done under such conditions that it is impossible to judge the relative importance of two or more factors operating at the same time. In most cases the exact composition of the mixture used was not known and in many cases the fact that quite different chemicals appear under the same name evidently was not even suspected. Some of the conclusions drawn are quite contradictory, and others, though perhaps correct, are based on so little evidence that their soundness is questioned. It is probably safe to say that at the time this investigation was undertaken at this station in 1912 enough correct conclusions on this subject had already been drawn to make certain phases of this work largely unnecessary if these correct conclusions had been recognized and isolated from the mass of apparently conflicting data and theories. Such a distinction had, however, been found impossible.

[1] Accepted for publication Sept. 2, 1922.

ARSENICAL COMPOUNDS USED AS INSECTICIDES

As some of the confusion on the subject of arsenical injury can be explained by a study of the processes of manufacture resulting in somewhat different compounds being sold under the same name, a brief review of these processes will be in order. It will also be necessary to discuss briefly the use of the more important arsenical insecticides that the significance of the work that follows may be evident.

ARSENIC TRIOXID

PREPARATION

Arsenic trioxid is obtained in large quantities as a by-product in roasting arsenical ores. This is not pure, but contains some metallic arsenic, arsenic sulphid, dirt, etc., from which it is purified by resublimation. There are two forms of the trioxid known, the amorphous and the crystalline. The amorphous changes slowly into the crystalline form under some conditions. At 25° C. the amorphous form is soluble in about 30 parts of cold water, while the crystalline requires about 100 parts. Both are slowly but completely soluble in about 15 parts of boiling water. The above proportions are approximate, as there seems to be a lack of agreement in the statements of various writers in regard to the solubility of the oxid. The name "arsenious acid," by which it is often referred, is a misnomer, since the oxid is an acid anhydride and has no acid properties until it unites with water, when arsenious acid is formed. In all probability the caustic effect of arsenic trioxid on vegetation is due to its combining with water and forming arsenious acid. Therefore the injury is proportional to the amount of arsenious acid formed and not to the amount of arsenic oxid in suspension.

USE AS AN INSECTICIDE

According to Bourcart (*1, p. 95*)[3] the first trials of using arsenic trioxid for spraying were conducted in America in 1867, when Markham used it to combat the Colorado potato beetle. On account of the serious injury occurring when it was used, other less soluble arsenical compounds were substituted until at the present time the oxid is used almost exclusively in the preparation of poison baits, and as a constituent in the preparation of some of the more usable arsenical compounds.

CALCIUM ARSENITE

Arsenite of lime was probably first recommended as an insecticide by Kilgore (*14*). He recommended that it be made by boiling together for one-half hour, in 2 to 5 gallons of water, white arsenic 1 pound, lime 2 pounds, and diluting the required volume to, say, 100 gallons. It is desirable that the lime should be present in the boiling solution of white arsenic, since it renders the latter insoluble as fast as it goes into solution, thus reducing the volume of water and shortening the time for obtaining the arsenite. Calcium arsenite is not manufactured for an insecticide, but many cases of foliage injury have been reported from its use, showing that it is more or less dangerous to use, and for this reason is not generally recommended.

[3] Reference is made by number (italic) to "Literature cited," pp. 535-537.

COPPER ACETO-ARSENITE (PARIS GREEN)

PREPARATION

Copper aceto-arsenite is a compound of copper, arsenic, and acetic acid, $Cu(C_2H_3O_2)_2.Cu_2As_2O_6$, and theoretically contains 58.65 per cent arsenious oxid (As_2O_3), 31.29 per cent copper oxid (CuO), and 10.06 per cent acetic acid, $C_2H_4O_2$. In the process of manufacture verdigris and arsenic trioxid are the essential materials. Generally verdigris is dissolved in acetic acid and added to a boiling solution of white arsenic and allowed to stand for some time to completely precipitate the copper aceto-arsenite. The light green precipitate is then thoroughly washed with hot water to remove the soluble salts.

Copper aceto-arsenite has several synonyms, the most important of which are Paris green, Schweinfurt green, and emerald green. The compound was discovered in 1814 during the course of experiments, with the object of preparing an improved Scheele's green or arsenite of copper for use as a coloring pigment in the arts. It is supposed to have been first made at Schweinfurt, Germany, but by whom is not recorded. On account of its poisonous nature its use as a pigment was limited, and at present it is scarcely used at all for this purpose, but has become one of the standard insecticide compounds, not only in this country but abroad.

USE AS AN INSECTICIDE

The history of the use of Paris green as an insecticide may be traced back to the period when the Colorado potato beetle became recognized as being of economic importance. The first published account of the destructive propensities of this beetle may be found in the Prairie Farmer, August 29, 1861, (7) and Paris green appeared upon the scene at some time between 1860 and 1870, but who first suggested it and who first used it for the destruction of the potato beetle will perhaps never be told. The use of this material as a standard insecticide undoubtedly began in the West Central States. At first the poison was applied in the powdered form, using flour, plaster, or ashes as a diluent. In 1872 Le Baron (*15, p. 116*), State entomologist of Illinois, in referring to the spring canker-worm, recommended that—

> strong washes, such as Paris-green water, or suds made from whale-oil soap, thrown upon the trees with a garden syringe, will also materially check their depredations.

This is probably the first statement in which the syringing or spraying of apple trees with Paris green is recommended. The first statement referring to the successful control of codling moth by the use of Paris green that attracted attention and which was followed by close investigation, appears to have been made by Edward P. Haynes (Lodeman, *16, 1910*) in 1878. After spraying his orchard with Paris green he said that it not only rid the orchard of cankerworms but the apples on the sprayed part were much less eaten by codling moths. However, the use of this poison for the destruction of foliage-eating insects was for various reasons adopted slowly, and it was not until about 10 years later that Paris green was freely recommended as one of the most valuable insecticides for the destruction of chewing insects.

FERROUS ARSENATE

The use of arsenate of iron as an insecticide in this country is in an experimental stage and this compound has been used to only a limited extent.

PREPARATION

In France, Vermorel and Dantony (*32*), who experimented with iron arsenate for several years, recommended that it should be prepared as follows in order to get the maximum adhesive power: 400 grams ferrous sulphate in 10 liters of water is added to an equal amount of arsenate of soda in 10 liters and stirred constantly. This stock solution is diluted to 100 liters and will contain about 200 gm. ferrous arsenate per hectoliter.

USE AS AN INSECTICIDE

Upon its use as an insecticide Smith (*28*) reports the use of arsenate of iron containing 45 per cent arsenious oxide on elm at the rate of 1¼ pounds to 100 gallons of water without injury, and that it had good insecticidal qualities. Vermorel and Dantony (*32*) used iron arsenate against the codling moth in 1906, 1907, and 1908 and concluded that the action of iron arsenate is equal or superior to lead arsenate, with the advantages of color, presence of iron versus lead, and cheapness. They concluded that the combination of iron arsenate with copper fungicides is not practicable, first, because such combination is not necessary, and, second, because it is very destructive to foliage, and recommend that iron arsenate be used alone and in no case combined with copper. Taylor (*31, p. 15*) reports the use of iron arsenate against the fall webworm in 1909, using 1 to 3 pounds to 50 gallons with promising results and no injury to peach foliage. Melander (*19*) says iron arsenate is a new spray that has the merit of cheapness, but that it is not on the market. He gives brief directions for its preparation, but does not discuss results obtained from its use. Scott and Siegler (*25*) concluded that iron arsenate was a slow-acting poison. In field tests on apple they found that it was not an effective insecticide for the codling moth used at the rate of 1 pound to 100 gallons. When used at greater strengths, however, they thought that it should give fairly satisfactory results, but that it would have no advantage over arsenate of lead.

LEAD ARSENATES

PREPARATION

Arsenate of lead for use as an insecticide is usually prepared by one of two methods, according to Haywood and McDonell (*12*). First, by using lead acetate and disodium arsenate when a precipitate of tri-plumbic lead arsenate, $Pb_3(AsO_4)_2$, is formed, or, second, by using nitrate of lead and disodium arsenate when a precipitate of diplumbic lead arsenate $(PbHAsO_4)_2$ is formed.

COMPOSITION

Theoretically the tri-plumbic lead arsenate contains 74.40 per cent of lead oxid (PbO), 25.60 per cent of arsenic oxid (As_2O_5), and 2.59 per cent water of constitution.

On account of various conditions, the commercial lead arsenate only approximates the percentages given above. This will be obvious for the following reasons: Chemically pure salts are too expensive to use in its manufacture, while various conditions such as temperature, concentration, etc., affect the reaction indicated by theory. Recent work by some investigators tends to show that the lead arsenate commonly on

the market is not either of the above forms, but is a double salt of a complex nature. For the purpose of this paper the lead arsenate will be designated as one of the above forms, or a mixture containing the two forms.

USE AS AN INSECTICIDE

Arsenate of lead was first used as an insecticide during the summer of 1893. In the early work of eradication of the gipsy moth it became evident that the known arsenicals could not be used at the requisite strength for killing gipsy moth caterpillars without serious injury to the foliage. Arsenate of soda was suggested as a substitute, but when used it burned the foliage to a greater extent than the other arsenicals. Mr. F. C. Moulton, who was experimenting upon these insecticides during the winter of 1892–93, proposed acetate of lead to precipitate arsenate of soda and in this way obviate the burning of the foliage caused by the latter; and by this method the first arsenate of lead was produced for insecticidal purposes. Arsenate of lead has the following advantages: (1) On hardy foliage it can be used at almost any desired strength without serious injury, (2) it is visible whenever used, and (3) it adheres well. The principal objection is its rather slow killing properties, probably due to its comparatively low arsenic content and slow solubility.

INJURY TO FOLIAGE

When lead arsenate was first used it was thought to possess all the necessary qualifications for an ideal insecticide. It has proved of great value and is used very extensively on apple and other more hardy foliage, but reports from its use on peach are variable, sometimes no injury being reported and in other cases the injury being so severe as to defoliate the trees. Fernald (*8*, *9*) states that—

> it [arsenate of lead] can be used in large proportions, if necessary, even up to 25 pounds to 150 gallons of water, without injury to the foliage. . . . It does not injure the foliage of the most delicate plants, even when used in as large a proportion as 25 pounds, or even more, to 150 gallons of water.

Smith (*26*, *p.* 437, *27*, *p.* 8) states:

> Its great advantage is its harmlessness to plant life of all kinds . . . it is absolutely harmless to foliage at any strength . . . It is the only effective poison of this character that can be safely applied to peach foliage and on conifers.

Many other statements similar to the foregoing are available to show that many considered lead arsenate as almost an ideal insecticide. However, other investigators conducting careful experiments occasionally reported serious injury. Haywood and McDonnell (*12*) say:

> Rather severe injury was caused to the foliage and fruit of the peach by pure lead arsenate, made either from lead acetate or lead nitrate.

Woodworth (*36*) states, in speaking of spraying in the Pajaro Valley with lead arsenate, that:

> While the codling moth was well controlled, the amount of burning was so large that the progress of spraying was entirely checked. . . . The most significant discovery of the year 1906 was that where a lead arsenate was so compounded that all the arsenic acid present was combined with lead no injury was produced on the most delicate foliage. Such a compound is known as the neutral or ortho-arsenate of lead. At that time no manufacturer was able or willing to produce an arsenate of lead of this description, and to this day, excepting the product manufactured here at Watsonville, there is no strictly neutral lead arsenate on the market.

These statements serve as illustrations that foliage injury is not due directly and entirely to the arsenical but is greatly influenced by other

conditions. Haywood and McDonnell (*12*) point out the great variation in the composition of the different samples analyzed, and this, no doubt, has had very much influence on contradictory results. Lead arsenates which are safe to use under dry arid conditions may cause serious injury under conditions of high humidity. Atmospheric conditions following sprayings have a great influence on the action of the spray mixture of the foliage, and for this reason duplicate experiments, when a short time intervenes between them, may not control. Gillette (*11*), Woodworth and Colby (*37*), and others concluded that leaves kept perfectly dry can hardly be injured by the arsenites, but that under conditions of high humidity the injurious action is greatly increased. However, at the present time lead arsenate is recognized as the standard insecticide, not only for orchard spraying but for field and truck crops as well. Against insects it is known as a rather slow poison, but it is effective. In this respect there is considerable difference in the two forms, viz, the triplumbic and the diplumbic ortho-lead arsenate, due in all probabilities to the difference in their arsenic content, which is the poisonous principle.

LONDON PURPLE

PREPARATION

London purple consists of calcium arsenite, calcium arsenate, and inert ingredients as dye residue, dirt, etc., and is prepared by boiling a purple residue from the dye industry with slaked lime. The analysis on a package recently received at this station was as follows: Total arsenic (As), 21 per cent; active ingredients, calcium arsenate and calcium arsenite, 54 per cent; inert ingredients, dyestuffs, etc., 46 per cent; arsenic (As) in water soluble forms, 7½ per cent. Analysis by our station chemist substantiated the claim as to the total arsenic content. If judged from the arsenic content, London purple has only about one-half the killing strength of Paris green when used as an insecticide.

USE AS AN INSECTICIDE

The name "London purple" was suggested by Dr. C. E. Bessey (private correspondence) in 1878, and he was the first to use it as a substitute for Paris green for the destruction of the potato beetle. Doctor Bessey was one of the three men who first received sample packets of London purple sent by a London firm [3] in a letter dated September 7, 1877.

On October 2, after an exchange of letters, the firm forwarded to him three kegs of the material, which was the first shipment sent to America. The results of the experimental work of Bessey and Budd were favorable to the new poison, and it was soon recommended as a substitute for Paris green, not only for the destruction of the potato beetle but for other insects as well.

The value of this material was recognized with surprising rapidity, probably due to its cheapness and the ease with which it could be applied. The principal objection to its use was its injurious action on the foliage of plants. Its burning tendencies were undoubtedly due to the soluble arsenic it contained, and it was not uniform in composition. The early analysis of London purple shows variations in amounts of arsenious oxid of from 31 per cent to nearly 60 per cent. However, at the present time the manufacturers claim to have perfected a process by which the composition of London purple is as uniform as that of Paris green or others of the standard insecticides.

[3] Hemingway & Co.

From about three years after its introduction, London purple was generally considered to be nearly equal in efficiency to Paris green, and it is so considered to-day.

ZINC ARSENITE

In 1903, an investigation of arsenicals and spray injury was begun by the California Experiment Station. In the course of this investigation, foliage tests were made with zinc arsenite in the summer of 1906. In 1907, about 5 acres of apple trees were sprayed during the blooming season without injury, and the results indicated that this material was a promising insecticide. In 1909, the first commercial material was prepared by the California Spray Chemical Company, Watsonville, Calif.

PREPARATION

The process of manufacture in general consists in boiling together in water, in the presence of ammonia, zinc oxid and arsenious oxid, in approximately the proportion of their combining weights. The boiling is continued until the oxids combine, which is indicated by a marked thickening of the mass, and until the filtrate shows only traces of arsenious oxid.

USE AS AN INSECTICIDE

At the present time zinc arsenite is used extensively in certain localities for the spraying of apple trees just after full bloom, at the rate of 3 pounds of the powder to 100 gallons of water. It is not used for later spraying on account of its tendency to injure foliage; but from recent tests it is possible that it will become an important insecticide for truck crops.

INJURY TO FOLIAGE

Luther (letter of May 20, 1910) advocated the use of zinc arsenite on apple, pear, bean, and potato, but not on delicate foliage like peach. Volck (*33*) pointed out what he believed to be a fallacy in accepting the foliage of any one plant as a reliable index to the injurious action of all arsenicals. He found that either bean or peach foliage was a suitable indicator for testing arsenate of lead that is intended for use on apples. Because of the great ease of obtaining bean foliage, it was adopted as a standard testing medium. Later he says:

> Arsenite of zinc may prove entirely neutral to bean foliage and yet when applied to peaches do marked injury. Samples which injure peach will later prove injurious to apples if applied in sufficient quantities, and bean foliage is not suitable for testing samples.

Luther (*17*) in speaking of investigations in the Pajaro Valley states:

> On apples it [zinc arsenite] has been sprayed as thick as whitewash without the least bit of injury. On small field crops, such as beans, potatoes, etc., it has given no injury, but on the peach, which is supposed to be more hardy than the bean, the injury was severe.

Woodworth (*36*), in speaking of spraying conditions in the Pajaro Valley, says:

> This [zinc arsenite] has proven to be the safest of the arsenicals that can be procured in the form of dry powder. It is not so safe, of course, as the neutral lead arsenates, but has been used without very serious evidence of burning in the orchards where dusting has been adopted instead of spraying. . . . There is no doubt that the zinc arsenite stands foremost at the present time among the available arsenicals with high arsenic content.

Cooley (*3*) reports its use on the foliage of potato and cabbage without injury. Johnston (*13*) reports the use of zinc arsenite in the proportions of 1, 1½, and 2 pounds to 50 gallons of water on potatoes, without foliage injury. Clinton and Britton (*2*) report two applications of zinc arsenite on apple trees at intervals of seven days, using ¾ pound to 50 gallons, with foliage injury so severe that the trees dropped many of their leaves. Volck (*34*) recommends the substitution of zinc arsenite for lead arsenate for the first two sprayings, i. e., full bloom and 10 days later, but in the following combination: Zinc arsenite (dry basis), 6 pounds; iron sulphid, 6 pounds; Black leaf 40, 1 pound; water, 200 gallons; because when iron sulphid is added, the foliage-injuring properties are largely restrained. If used alone, only the first (full bloom) spraying should be applied. For later sprayings arsenate of lead is recommended.

Melander (*19*) says "It [zinc arsenite] is easy to use, adhesive, and has not scorched in our tests [on apple]." Schoene (*24*) found that on apples zinc arsenite alone or in combination with soap, glucose, or lime sulphur caused more or less injury, but that lime or Bordeaux prevented this injury. In other experiments with zinc arsenite, slight injury occurred on the foliage of pear and plums, peach and grape leaves were severely scorched, while potatoes and cabbage were uninjured. It is also suggested in this bulletin that the solvent action of carbonic acid is partly responsible for the damage. Scott and Siegler (*25*) record injury to foliage of apple when zinc arsenite was used alone at the rate of ¾ pound to 50 gallons of water or combined with milk of lime or with lime sulphur; that it caused moderate burning on bean foliage, except where lime was added, in which case no burning resulted; that when added to slaking lime for Bordeaux mixture it caused no foliage injury to either apple or grape; and they suggested its possible use with Bordeaux mixture in certain sections for the control of codling moth, bitter rot, and blotch.

By various workers zinc arsenite is considered an effective insecticide against insects that are rather resistant to the poisoning effect of arsenic, such as larvæ of webworm, tussock moth, etc.

METHODS OF INVESTIGATION

It has been apparent for some time that there are several factors that influence the injury of foliage by arsenical compounds. Some of these are inherent in the plants themselves, some are dependent upon the chemical nature and solubility of the compounds used, while still others are to be classed as environmental conditions. It is obvious that to determine the relative importance of these several factors one of them must be varied while the others are kept as nearly constant as possible, for it is quite impossible to eliminate all but one.

METHODS OF APPLYING CHEMICALS

A large part of the spraying was done in the college orchard at Bozeman, Mont.; but this was quite extensively supplemented by orchard work in other parts of the State, and by spraying plants of various kinds in field plots, on the college campus, and in the botanical greenhouse.

The mixtures were applied with a bucket spray pump under good pressure, using a Bordeaux nozzle. In the case of small plants, such as potatoes, sugar beets, etc., entire plants were sprayed, but on orchard trees this was rendered impossible by the very large number of applications

that were made, reaching into thousands. In orchard spraying, therefore, a single branch 2 or 3 feet long was sprayed with each mixture, and it is probable that as accurate results were secured as though entire trees had been covered. Indeed, it was possible to cover these single limbs more evenly than whole trees could have been covered.

It has been found most convenient to use two liters of spraying mixture for each application, and for this reason the strength of the chemical used is indicated as the number of grams in two liters. This method of expression will be found in most of the tables in this paper.

PRECAUTIONS

Care was taken to avoid spraying on windy days, and if rain followed the application the results were rejected excepting as they could be used for data in relation to precipitation. For the regular work foliage was chosen that was normal in development and free from mechanical or other injuries. Both the upper and the under side of every leaf was drenched thoroughly, and except in special cases care was taken not to shake off the spray mixture before it dried upon the leaves.

As the number of applications exceeded 6,000 in the orchard and plots and 4,000 in the greenhouse, it is evident that the greatest care was necessary to prevent errors in labeling, recording, etc., if the results were to be thoroughly reliable. This was realized from the first, and a complete and yet simple system of checking was adopted and scrupulously followed. From the nature of this system and from the fact that in the checking an error in the original record was very rarely found, we feel assured that the few erratic results that appeared were all due to other causes.

In presenting these data comparisons are not made in the same table between tests run under different conditions, and the reader is warned not to make direct comparisons between injuries which resulted from spraying on different dates, in different places, or under other differing conditions, except for the purpose of studying the effects of these specific conditions, others being practically constant.

DEVELOPMENT AND CHARACTER OF INJURY

When a leaf is materially injured by arsenic, it shows visible symptoms in a day or two which become more and more pronounced until certain portions or, in severe cases, the whole leaf is dead, brown, and more or less shriveled. In severe cases the leaves drop in from one to four weeks from the time of treatment. Most commonly the first visible symptoms appear on the second day after treatment. At this stage there is very little change in color, but the surface of the leaf in the injured portion has lost its normal luster and becomes duller in appearance. The tissues under these duller areas have lost much of their turgidity and become more or less flabby. Very soon, perhaps the second day, a dull brown tinge is apparent, which at first is indefinite in outline and becomes more and more sharply defined. After 10 days of treatment no further change takes place except that the dead portion becomes frayed by the whipping of the leaves in the wind, or, if it is severely injured, the leaf drops off. No exact time can be given for this course of development, as it is hastened by hot, dry weather and retarded by cool, wet weather. Most commonly the first visible injury may be detected on the first or the second day. The condition shown in Plate 1, A may be seen on the

third day; Plate 1, B on the fourth day; Plate 1, C on the fifth day; Plate 1, D at the end of a week; Plate 1, E in about 10 days, and Plate 1, F in 3 or 4 weeks.

If the leaf is not entirely killed, as was usually the case in these experiments, the injury is worse at the margin and in roundish spots of all sizes in the interior. If there are abrasions through the epidermis, these become centers of discolored areas. In most of these spots, however, there is no visible mechanical injury, nor do they correspond to depressions in the leaf where the spray mixture collected in greater abundance.

The degree of injury was measured by the proportions of injured to uninjured surface. In the case of the apple, if more than half of the leaf is killed it usually drops prematurely. The position of the injured area varies this rule somewhat. Injury near the midrib or near or on the petiole is more likely to cause dropping than if on the margin, especially toward the tip. Not all plants are equally inclined to shed their leaves. The bean, for example, will do so much more readily than the apple, while the tomato retains them more tenaciously.

For the purpose of comparing results for tabular data, etc., a condensed method of expressing the degree of injury is highly desirable. For this purpose the terms, very slight, slight, moderate, bad, very bad, partly defoliated, and defoliated were adopted. As applied to individual leaves the following definitions apply to the records in this paper:

Very slight = the least amount of injury that is easily seen.

Slight = a few small spots up to one-eighth of the area of the leaf killed.

Moderate = one-eighth to one-fourth of the area killed.

Bad = one-fourth to one-third of the area killed.

Very bad = one-third to nearly all of the area killed.

As applied to the sprayed plants or branches as a whole the following definitions served as a guide:

Very slight = a few small spots on a small proportion of the leaves; no leaf seriously injured.

Slight = about one-eighth to one-fourth of the leaves showing spots, but few, if any, of them seriously injured.

Moderate = about one-third of the leaves more or less injured. Most of the leaves showing only small spots, but a few of them may be injured to the degree classed as "bad." In the definitions given above for individual leaves we have applied this term to the most serious injury that can be done without commercial injury to most crops.

Bad = approximately half the leaves injured, most of them only slightly, but some in "moderate" degree. This we have considered to be just enough injury to class as of commercial importance to most crops.

Very bad = most of the leaves more or less injured, some of them nearly killed.

Partly defoliated = a portion, but not all of the leaves entirely killed or so badly injured that they dropped off before the notes were taken. The leaves of some kinds of plants when all or nearly all the tissue is killed, will drop off. The leaves of other plants, as tomato, still cling after death, but for uniformity we class as defoliation a killing of the leaves whether they actually drop off or not.

Defoliated = practically all the leaves are killed.

Occasionally there would be some combination of injured leaves other than those listed above, as, for example, a few leaves badly injured and the others practically all sound, and judgment had to be used in designating the degree in such cases, but these definitions will, in general, serve to place the authors and readers on common ground.

CONDITIONS AFFECTING THE AMOUNT OF INJURY

It is a well-recognized fact that arsenic and its compounds tend to injure all forms of life with which they come in contact, but the degree of injury varies with several conditions, some of which are more or less under the control of the entomologist, the horticulturist, or the farmer, who makes use of these compounds for destroying insects upon growing crops. A study of these conditions constitutes the most important part of this investigation.

DIFFERENCE IN SUSCEPTIBILITY OF PLANTS

It has been found that different species of plants vary greatly in their natural resistance to arsenical action. Confining ourselves to the higher plants and especially to those that for economic reasons are likely to receive applications of arsenical insecticides, we find that some will be almost or quite killed by applications that will injure others but little.

DIFFERENCE IN GENERA AND SPECIES

Numerous spraying tests were made on a rather wide range of plants, including some that were only distantly related. Table I, which records the results of a test made on August 2, 1915, is fairly typical of the results obtained with these plants. It should be added, however, that in other tests sugar beet has not usually proven quite as susceptible as here indicated, being about the same as potato. Also, squash has usually proven a little more susceptible, being in about the same class as apple. Cabbage is distinctly the most resistant of the plants we have tested, though in the experiment recorded in this table cucumber was injured but little more.

TABLE I.—*Plants in field plots sprayed with calcium arsenite, 1.2 gm., and soap, 7.2 gm. per liter of water, to show the relative susceptibility of different species*

Name of plant.	Injury.
Apple, Wealthy	Bad.
Bean, White Navy	Very bad.
Cabbage, Late Flat Dutch	Slight.
Cucumber, Improved Long Green	Do.
Potato, Early Ohio	Moderate.
Pea, Senator	Bad.
Rutabaga, Monarch	Moderate.
Squash, Yellow Crookneck	Do.
Sugar beet, Klein Wenzlebener	Bad.
Tomato, Enormous	Moderate.
Turnip, White Globe	Do.

We suggest a table of susceptibility of plants we have sprayed, as shown in Table II. In using this table one must keep in mind that different varieties of the same crop vary somewhat among themselves in this respect. In this table an attempt is made to range the plants from the most resistant to the most sensitive.

TABLE II.—*Approximate order of foliage susceptibility to arsenical injury*

1. Cabbage.	6. Tomato.	11. Pea.
2. Sugar beet.	7. Rutabaga.	12. Squash.
3. Potato.	8. Turnip.	13. Cucumber.
4. Apple.	9. Cherry.	14. Peach.
5. Pear.	10. Plum.	15. Bean.

Something about the condition of plants of the same kind seems to vary at times to make them more or less susceptible. This accounts for some apparent discrepancies between Tables I and II. Repetition for confirmation is recognized as of fundamental importance in all scientific experiments, but is indispensable in studies of arsenical injury.

TABLE III.—*Fruit trees sprayed with copper aceto-arsenite and with calcium arsenite to show relative susceptibility of different species*

Name of tree.	Injury.	
	Copper aceto-arsenite 2.4 gm. to 1 liter of water.	Calcium arsenite 1.2 gm. to 1 liter of water.
Apple, McIntosh	Very slight	Moderate.
Crab apple, Transcendent	None	Do.
Cherry, Montmorency	Moderate	Very bad.
Cherry, Royal Ann	Slight	Nearly defoliated.
Pear, Flemish Beauty	Very slight	Moderate.
Plum, Bradshaw	Very bad	Defoliated.

For the variety used, the order of injury here indicated is plum, cherry, pear, apple, and crab, of which the plum is distinctly most susceptible. From the conflicting reports of other investigators it seems likely that this order will vary according to the variety used. We made no tests on the peach, as no trees were available, but it is quite generally conceded that it is more tender than any of the fruits named in Table III.

Roses were sprayed several times for a comparison with apple. Harrison's yellow rose seemed about like Okabena apple in susceptibility, and the Rugosa a little more tender.

DIFFERENCES IN VARIETIES OF THE SAME SPECIES

It is important to know if arsenical spray injury on any variety that happens to be chosen will be the same on other varieties under similar conditions. Among apples it is quite generally conceded that Ben Davis is especially susceptible, though strictly comparative data are not abundant in the literature.

In our work we have had many opportunities for comparing susceptibility of apples, and we have thoroughly tested Alexander, Ben Davis, Charlottenthaler, Gano, Hybernal, Lieby, McIntosh, McMahon, Okabena, Oldenburg, Rome, Shiawassee, Wagener, Tetofsky, Yellow Transparent, Greenwood, Crab, Hyslop crab, and Transcendent crab. Of these the crab apples have shown themselves distinctly more resistant than the standard apples, especially the Transcendent, which is almost in a class by itself. Among the standard varieties Ben

Davis, Gano, and Tetofsky have been conspicuously susceptible, while the others have shown no very consistent differences. They are so nearly alike that in one test certain ones would be injured a little more than the rest, while in other tests other varieties would be most injured. For practical purposes they may be considered about alike. It seems probable that this varietal susceptibility of apple trees is due to the thickness or character of the cuticle on the leaves rather than to a difference in the living cells within, for we have shown (*30, p. 304*) that when fresh wounds through the bark are treated with arsenical compounds, Ben Davis is not more injured or Transcendent less injured than other varieties.

Of the common garden beans, four varieties were compared. These were the White Navy, Red Kidney, Dwarf Horticultural, and Burpee Stringless. In their susceptibility to calcium arsenite, copper acetoarsenite, and London purple they were almost identical.

From our experiments and those of Woodworth (*35*) we may conclude that among plants of different species, and different varieties of the same species, few general rules may be laid down, and each species and variety must be actually tested in comparison with others to know its susceptibility. To be sure, some groups, as beans, are especially susceptible (probably all of them) and probably all cabbages are relatively resistant. But among plants of intermediate susceptibility such as apple, cherry, rose, potato, and sugar beet, varietal difference is sufficient to make it unsafe to draw comparisons between these species without stating the varieties.

INDIVIDUAL DIFFERENCES

Do individuals of the same species and variety show differences in susceptibility? If such be the case, general conclusions can not be drawn with safety from single tests, and some repetition is necessary to get the prevailing tendency, the amount of repetition depending upon the degree and frequency of individual variation and the exactness of the method used.

In carrying on this investigation, practically all the herbaceous plants used, whether in the greenhouse or in the field plots, were sprayed in triplicate and in some cases three branches of as many different orchard trees were sprayed in the same way. Opportunity was thereby offered for a very large number of comparisons. The results showed that the tendency to individual variation is quite marked. As this tendency is a matter of degree and we have no standards for expressing it, reference may be made to Table IV, which is quite representative of this condition. (See also Tables IX to XIV.) Doubtless this variation is partly apparent and partly real. With the greatest of care it is difficult to keep a large number of plants under identical conditions after spraying. One may be kept in a little more shaded place than another, or have better air circulation, or be brushed more in working among the plants. This difficulty is even greater in treating branches of orchard trees. Using every precaution to eliminate such factors, individual differences still appeared sufficient in degree to convince one that the triplicate plants at the time of spraying were not always alike in susceptibility. We believe that this is due in part to the environmental conditions under which the plants were grown, though all showing visible abnormalities were rejected before spraying, and there also may be a natural tendency to more or less resistant strains.

Nevertheless, the investigator in this field must give it due recognition and repeat all work until a predominant tendency is clearly established. We have made it a point, therefore, in all cases in which certain results shown in a published table differed from those most commonly observed under the same conditions, to call attention to this fact.

TABLE IV.—*Tomato plants in greenhouse, sprayed in triplicate, showing individual differences in susceptibility*

Chemical.	Amount of chemical in 2 liters of water.	Amount of soap in 2 liters of water.	Injury.		
			Plant 1.	Plant 2.	Plant 3.
	Gm.	*Gm.*			
Lead arsenate, diplumbic, Baker.	9.4	0	None	None	None.
	9.4	7.2	....do	....do	Do.
	9.4	14.4	....do	....do	Do.
	9.4	28.8	Moderate	Moderate	Moderate.
Calcium arsenate, Merck.	2.8	0	Very slight	Very slight	Very slight.
	2.8	7.2	Moderate	Slight	Slight.
	2.8	14.4	Slight	....do	Do.
	2.8	28.8	Moderate	Moderate	Moderate.
Calcium arsenite, Adler.	2.4	0	Moderate	Moderate	Moderate.
	2.4	7.2	Bad	Bad	Bad.
	2.4	14.4	Very bad	Very bad	Very bad.
	2.4	28.8	Partly defoliated.	Partly defoliated.	Partly defoliated.
Calcium arsenite, Baker.	2.4	0	Moderate	Moderate	Moderate.
	2.4	7.2	Very bad	Very bad	Very bad.
	2.4	14.4	....do	....do	Do.
	2.4	28.8	....do	....do	Do.
Calcium arsenite, Merck.	2.4	0	Slight	Slight	Slight.
	2.4	7.2	....do	Moderate	Do.
	2.4	14.4	Very slight	Very slight	Very slight.
	2.4	28.8	....do	Slight	Moderate.
Arsenic trisulphide, Baker.	0.8	0	None	Slight	Very slight.
	.8	7.2	Slight	....do	Moderate.
	.8	14.4	Moderate	Moderate	Slight.
	.8	28.8	Very bad	Very bad	Very bad.

DIFFERENCES IN PARTS OF THE PLANT

In the spraying of trees and other plants all aerial portions are necessarily coated. This may or may not be necessary from the standpoint of controlling insects and diseases, but as it is practically unavoidable it makes the relative susceptibility of different parts of the plant to injury by the spray mixture of much importance in all spraying operations. This is especially true of fruit trees where, for example, the fruit may be russeted by Bordeaux mixture, greatly reducing its market value, while the same amount of burning on the leaves is unimportant.

STEMS, FRUIT, AND FOLIAGE

On all kinds of plants sprayed in this investigation the leaves were the most susceptible portion. Most of the herbaceous plants bore no fruit prior to the time of spraying, but beans, cucumbers, and squashes were, in a few cases, exceptions. On apple trees the leaves proved much more tender than either stems or fruits. This is true to such a marked degree that any arsenical treatment that caused even the slightest direct damage to fruit or bark nearly defoliated the sprayed branch. So far as this fruit is concerned, therefore, and probably in general, arsenical spray injury is a problem of foliage injury almost exclusively. The apple fruit proved slightly more susceptible to very severe treatment than the most tender portion of the bark on the stem.

We have frequently noted that with plants of all kinds, whether herbaceous or woody, the youngest portion of the stem is the most easily injured. With leaves, however, this is not the case. Old leaves nearly ready to fall are damaged most, while young ones just expanding are most resistant.

On the apple the foliage injury takes place almost exclusively through the lower epidermis. Gillette (*10*) sprayed the upper surface and then both surfaces by way of comparison and found that—

> wherever this was done, the damage sustained by the leaves that were wet on both sides was fully double that sustained by those wet only on the upper surface.

Woodworth (*35*) tried painting the leaves with white arsenic, Paris green, and London purple, some on one surface, some on the other, and some on both. The entire surface was coated. He concluded that the lower side is more susceptible than the upper, the difference in his experiments being in the proportion of 47 to 22.

In our own work the arsenical was applied individually to many leaves with a very soft brush, some to the upper side and others to the lower side. It was found that if the painted area extended to the margin it was practically impossible to keep a little of the liquid from extending over onto the opposite surface from that intended. Therefore, after a few preliminary experiments the practice was followed by painting a strip about ¾ by 1 ¼ inches down one side of the midrib. This strip never approached the leaf margin. In Table V each report represents the injury of 10 painted leaves on one shoot. Both sodium arsenite and calcium arsenite were used in this experiment, one being a soluble and the other a nearly insoluble compound. Soap was added in some cases to cause the liquid to spread better and to penetrate the pubescence on the leaf more readily.

The results shown in Table V are quite typical and indicate that the arsenical injury to apple foliage from spraying is brought about largely by absorption from the lower surface. Indeed, in some of our experiments when very toxic solutions were used no trace of injury occurred on leaves treated on the upper surface. We are led to believe that in those cases where injury did occur after treatment of the upper surface, there was some tiny abrasion, not easily visible to the naked eye. In view of our results it is difficult to account for so much injury from treating the upper surface as reported by Woodworth (*35*). The only essential difference in method was that he painted the whole surface instead of the central portion only. When we did the same we could not readily avoid getting some of the liquid over the margin onto the

other side with consequent injury and this may explain the discrepancy. Also, in his experiments the epidermis treated may not have been so free from tiny abrasions.

TABLE V.—*Leaves of apple treated on the upper or the lower surface to determine the relative injury*

Variety.	Chemical.	Strength.	Injury.	
			Upper.	Lower.
Transcendent	Calcium arsenite.	1–1,000	Very slight	Very slight.
Wealthy			None	Very bad.
McIntosh			Very slight	Moderate.
Yellow Transparent			None	Very slight.
Transcendent	Calcium arsenite plus soap.	1–1,000 (14.4 gm. in 2 liters).	None	Very slight.
Wealthy			....do	Do.
McIntosh			....do	Do.
Yellow Transparent			....do	None.
Transcendent	Calcium arsenite.	1–500	Very slight	Slight.
Wealthy			None	Do.
McIntosh			Very slight	Very bad.
Yellow Transparent			None	Slight.
Transcendent	Calcium arsenite plus soap.	1–500 (14.4 gm. in 2 liters).	None	Slight.
Wealthy			....do	Moderate.
McIntosh			....do	Very slight.
Yellow Transparent			....do	Partly defoliated.
Transcendent	Sodium arsenite.	1–1,000	None	Moderate.
Wealthy			Very slight	Very bad.
McIntosh			None	Bad.
Yellow Transparent			Very slight	Do.
Transcendent	Sodium arsenite plus soap.	1–1,000 (14.4 gm. in 2 liters).	None	Slight.
Wealthy			....do	Moderate.
McIntosh			Very slight	Partly defoliated.
Yellow Transparent			None	Defoliated.
Transcendent	Sodium arsenite.	1–500	Slight	Bad.
Wealthy			None	Very bad.
McIntosh			Moderate	Partly defoliated.
Yellow Transparent			Slight	Very bad.
Transcendent	Sodium arsenite plus soap.	1–500 (14.4 gm. in 2 liters).	Very slight	Very bad.
Wealthy			None	Partly defoliated.
McIntosh			Slight	Do.
Yellow Transparent			None	Defoliated.

Whether the under surface of apple leaves is more susceptible to injury because of the greater prevalence of stomata or because of a thinner or more permeable cuticle is yet to be determined. We are inclined to the latter view.

To determine if this greater protection of the upper epidermis is found also in other plants the leaves of a dozen different shrubs and trees on the college campus were painted with sodium arsenite and soap in different strengths. The procedure was the same as described for apple on page 515. These plants are as follows: Alder, barberry (common, green), birch (white), box elder, buckthorn (English), chokecherry, dog-

wood, lilac (purple), lilac (white), maple (Norway), Siberian pea tree, willow (golden). Repeated tests showed that in all species tested the upper epidermis is decidedly more protective against arsenical injury than the lower.

RELATIVE INJURIOUSNESS OF ARSENICAL CHEMICALS

When a number of arsenical compounds are sprayed upon plants the relative injury done by them may be influenced by two factors, (1) their relative solubility and (2) their relative toxicity to the plants treated. It so happens that with reference to solubility, arsenical compounds fall into two fairly well defined groups, those that dissolve readily in a relatively small amount of cold water and those that are only slightly soluble in cold water. The former we will for convenience designate as the soluble arsenical compounds and the latter as the insoluble arsenical compounds, it being fully recognized that a small amount goes into solution while the greater part remains undissolved when used in spraying work.

READILY SOLUBLE ARSENICAL COMPOUNDS

Compounds of this class can not be used for spraying plants to control insect pests owing to the injury done when enough is applied to kill the insects. Their practical significance in this connection lies in their utility as weed killers and in the possibility of their presence as impurities in the so-called insoluble arsenical insecticides. Their toxicity may be compared on either of two bases, (1) using equal parts by weight of the different chemicals or (2) such amounts of them as will contain equal amounts of arsenic. Our experiments included tests on both these bases.

The results shown in Tables VI and VII correspond very well with those that were usually found in the many tests of these compounds. It will be noted that on the basis of toxicity whether equal weights of the chemicals be used per liter or amounts to contain equal weights of arsenic, these compounds may be divided into three groups; cacodylic acid and the cacodylates are most toxic, the arsenites and arsenic acid next, and the arsenates least. Ammonium arsenate constitutes one exception; as it causes injury equal to the arsenites. Ammonium arsenite was used a little, but is unsatisfactory owing to its instability.

TABLE VI.—*Apple sprayed with soluble arsenical compounds using the same number of grams for 2 liters*

Chemical.	Injury.		
	Concentration 1 to 10,000.	Concentration 1 to 5,000.	Concentration 1 to 2,000.
Acid, arsenic	None	Slight	Bad.
Acid, cacodylic	Moderate	Moderate	Very bad.
Ammonium arsenate	None	do	Bad.
Potassium arsenate	do	None	Moderate.
Potassium arsenite	do	Very slight	Bad.
Potassium cacodylate	do	Moderate	Very bad.
Sodium arsenate	do	None	Slight.
Sodium arsenite	do	Very slight	Bad.
Sodium cacodylate	do	Moderate	Very bad.

TABLE VII.—*Apple and tomato sprayed with soluble arsenical compounds in amounts to contain 7.5 gm. of arsenic in 2 liters of solution*

Chemical.	Injury.	
	Apple.	Tomato.
Acid, arsenic	Very bad	Very bad.
Acid, cacodylic	Defoliated	Partly defoliated.
Ammonium arsenate	Partly defoliated	Very bad.
Potassium arsenate	Bad	Bad.
Potassium arsenite	Partly defoliated	Very bad.
Potassium cacodylate	Defoliated	Partly defoliated.
Sodium arsenate	Moderate	Bad.
Sodium arsenite	Partly defoliated	Very bad.
Sodium cacodylate	Defoliated	Nearly defoliated.

Cacodylic acid and the cacodylates probably never occur in insecticides and are too expensive to be used as weed killers, and are therefore of more theoretical than practical interest. The scientific interest which they have in this connection lies chiefly in their very high toxicity to higher plant life and relative low toxicity to higher animal life. Cushny (*6*) states:

> The action being due to the ion and not to the element . . . organic arsenic combinations in which the metallic atom is directly attached to the carbon atom are only feebly poisonous. ..... The earliest of these is sodium cacodylate, $(CH_3)_2AsOONa$.

Merck's Index (*20*) states also:

> The cacodylates (which see) are now largely used instead of the alkali arsenites, as the former are far less toxic.

It has been stated on high authority (*23*) that—

> Arsenious acid is extremely poisonous, whereas many, both of higher and of the lower plants, can withstand large doses of arsenic acid and can accumulate large quantities of arsenic when supplied to them in this form.

This statement, while perhaps true under some conditions, is wholly misleading if applied to spray mixtures.

NEARLY INSOLUBLE ARSENICAL COMPOUNDS

Turning to the arsenical compounds that are but slightly soluble, we find the comparison more difficult. In the first place it is hard to get these chemicals that are pure and of definite composition, and in some instances they are not fully named. For example, a "lead arsenate" may be diplumbic ortho-lead arsenate or triplumbic ortho-lead arsenate or a mixture of the two, and neither the label nor the statement of the manufacturers reveals which of the three it is. Indeed, it is doubtful if an absolutely pure diplumbic or triplumbic lead arsenate is now on the market. Then, too, some of these chemicals are so slightly injurious that they cause no injury except under such conditions as will permit the more injurious ones to nearly or quite defoliate the plants or branches, making fine comparisons difficult. Furthermore, the number of chemicals in this group is so large, especially if we use several brands of the more important ones, that no single series of comparative tests is likely to be reliable throughout, owing to individual differences in the plants used, unless several are sprayed at the same time with each mixture,

making a series so large that the last must be applied much later than the first. Table VIII will, however, give a nearly correct idea of their relative injuriousness. Under the conditions governing these experiments it should be constantly kept in mind that these results might be different if other brands of the chemicals were used or if climatic conditions were different.

If we consider the results shown in this table and also those from many other spraying tests, we come to the conclusion that the order of injuriousness of the chemicals listed in Table VIII when sprayed on to foliage under our conditions is as follows:

1. Calcium arsenite.
2. Arsenic trisulphid.
3. Barium arsenate.
4. Calcium arsenate.
5. Lead arsenite.
6. Copper aceto-arsenite.
7. Arsenic disulphid.
8. Arsenic trioxid.
9. Zinc arsenite.
10. Lead arsenate diplumbic.
11. Lead arsenate triplumbic.
12. Ferrous arsenate.

TABLE VIII.—*Results of spraying different plants with "insoluble" arsenical compounds in such amounts as to give equal weight of arsenic to 2,000 cc. water to show relative toxicity*

Chemical.	Injury to bean, May 3, 1915 (1 gram arsenic in 2 liters of water).	Injury to apple, June 18, 1915 (2 grams arsenic in 2 liters of water).	Injury to tomato, Aug. 14, 1916 (2 grams arsenic in 2 liters of water).
Arsenic trioxid, Baker	Very slight	None	None.
Arsenic disulphid, Merck	do	do	Do.
Arsenic trisulphid, Baker	Bad	Slight	Very bad.
Barium arsenate, Adler	Moderate	Moderate	Bad.
Calcium arsenate, Merck	do	do	Moderate.
Calcium arsenite, Baker	Defoliated	Partly defoliated.	Partly defoliated.
Ferrous arsenate, Merck	Very slight	None	None.
Lead arsenate, diplumbic, Baker	do	do	Do.
Lead arsenite, Merck		do	Very slight.
Lead arsenate, triplumbic, Baker	None	do	None.
Paris green, Baker	Moderate	Moderate	Do.
Zinc arsenite, "Ortho 40"	Very slight	Slight	None.

Probably the most striking fact brought out by this phase of the work is that arsenic trioxid may be applied with so little injury. It is well known that this compound has been kept out of general use by the injury it has caused under field and orchard conditions in other localities. We have sprayed both apple and several herbaceous plants many times and on many dates during a period of several years and have never found it especially injurious if the mixture was applied as soon as prepared. This might not be true in localities with a high humidity. Even the freshly prepared amorphous form which is more soluble than the crystalline form has given less injury than the majority of the slightly soluble arsenical

compounds, and indeed it was scarcely more injurious than the crystalline form.

On the other hand, it seems surprising that calcium arsenite could have remained in use as an insecticide for so long as it did. It has gradually been abandoned, partly because of its burning of the foliage and partly because some time is consumed in its preparation according to the Kedzie (Woodworth and Colby (*37*)) or the Kilgore (*14*) formulas, which are the ones most generally followed. We have tried three different brands, one of them especially prepared for our use, besides the home-made articles prepared after the Kedzie and the Kilgore formulas, and are left no other alternative than to place it at the head of the list of slightly soluble arsenical compounds, considered from the standpoint of injurious properties. Indeed, used in strengths to contain equal amounts of arsenic, the home-made calcium arsenites were even more harmful than the Baker brand on which we based most of our work.

To determine the variability of compounds supposed to be identical, tests were made with different brands of calcium arsenite, lead arsenate, zinc arsenite, and arsenic trioxid, using four brands of calcium arsenite, 4.9 gm. to 2 liters of water, and applying to apple foliage. Of the four, one[4] caused in a typical case moderate injury; the second,[5] very slight; the third,[6] bad; and the fourth,[7] very slight. In this case there was no consistent relation between the arsenic content of the different brands and the amount of injury produced.

More than 30 brands of lead arsenate were tried. Some were supposed to be diplumbic, others triplumbic, and others mixtures of the two, while still others gave no clue without chemical analysis as to their kind. Some were paste and others were dry. Some were prepared for use as insecticides and others as pure chemicals for technical use. It is doubtful if the results of these tests merit publication in tabular form. Marked differences were found, to be sure, but as some factories do not put out a uniform product, and as others have changed their processes of manufacture since the tests were made, and still others will doubtless do so in the near future, such a list could not safely be used as a basis for selecting lead arsenates for orchard spraying. The same could, perhaps, be said also of the calcium arsenites and zinc arsenites discussed above. The important point is that lead arsenates do vary in composition, as indicated by their analyses and by their injurious properties, even though the labels would not indicate the fact.

It is generally believed that diplumbic lead arsenate has a greater tendency to injure foliage than the triplumbic form. This is doubtless true in a general way, but we have had some brands of the diplumbic that were just as safe to use as most of the brands of triplumbic arsenate.

Four lots of arsenic trioxid were compared, a crystalline form and an amorphous form from one manufacturer,[8] a crystalline form from another,[9] and a crystalline form taken direct from the arsenic retainer of a smelter[10] situated at Anaconda, Mont. In addition, an arsenic trioxid paste was made from each of these four by grinding the dry powder in a mortar with a little water. This was allowed to stand a week or more before using. The injury caused by these various lots of arsenic trioxid was practically equal.

[4] Adler's.
[5] California Spray Co.'s "Ortho 40."
[6] Sherwin-William's.
[7] Thomson's.
[8] J. T. Baker.
[9] Merck.
[10] The Washoe.

EFFECTS OF ADDING OTHER INSECTICIDES, LIME, ETC.

In orchard, field, and garden practice it is often desired to add various substances to arsenical spraying mixtures. These substances are of various kinds: Other insecticides, or fungicides for combination sprays, soap, or other colloidal substances for an adhesive or "spreader" on such plants as cabbage and sugar beet to retard the settling of the arsenical suspension, as recommended by Parker (*22*), or various materials to lessen the tendency to burn the foliage.

LIME SULPHUR

The addition of lime sulphur to kill scale insects or to prevent apple scab is often desirable. This substance brings about a chemical reaction with most arsenical insecticides, and it is of interest to know whether the insecticidal and fungicidal properties of either or both are destroyed and whether the tendency to burn the foliage is increased or decreased. The first of these questions has been quite thoroughly discussed by Cordley (*4*) and Melander (*18*) and is hardly within the province of this paper. The effect of lime sulphur on the injury caused by the different arsenicals is shown in Table IX. The tests from which this table was prepared ran through three seasons and were carried on in four different parts of the State. Several brands of the chemicals were used. The arsenicals were used in such strengths as to contain either 1 or 2 grams of arsenic for each 2 liters of water. The lime sulphur (factory boiled) was added at the rate of 77 cc. of 28° Baumé in every 2 liters of mixture. If in any case the lime sulphur (control) alone caused injury, the series was rejected, but this was extremely rare.

TABLE IX.—*Effects of lime sulphur on the burning properties of various arsenical compounds*

Arsenical compounds to which lime sulphur was added.	Number of brands.	Number of applications.	Number of times injury increased.	Number of times injury decreased.	Number of times the same.	Number of times no injury with or without.
Arsenic trioxids	2	3	2	0	1	0
Arsenic disulphid	1	2	2	0	0	0
Arsenic trisulphids	2	4	3	0	1	0
Barium arsenate	1	1	0	0	1	0
Calcium arsenites	3	16	2	9	3	2
Copper aceto-arsenite	2	20	12	2	2	4
Ferrous arsenates	3	8	0	1	0	7
Lead arsenates, triplumbic	8	52	25	0	1	26
Lead arsenates, diplumbic	13	85	36	0	0	49
Lead arsenates, mixtures	10	27	15	0	1	11
Zinc arsenites	6	42	10	3	2	27

From Table IX it may be seen that lime sulphur causes an increase in the injury produced by most arsenical compounds. This is especially true of copper aceto-arsenite, the lead arsenates and zinc arsenite. With calcium arsenite, however, it usually causes a reduction in the amount of injury, though not to such an extent as to make this compound

safe to use. Even with lime sulphur added calcium arsenite does more damage to the foliage than any other arsenical in the list given in Table IX.

We have given some attention to finding an explanation for the reduced injury by calcium arsenite when lime sulphur is added. As a principle of physical chemistry, the lime sulphur containing calcium sulphids, which are more readily soluble than calcium arsenite, would be expected to prevent to some extent the ionization of the less soluble salt. If this were the only consideration involved, other soluble calcium salts would be expected to have the same effect. To test this experimentally we added calcium nitrate to certain lots of calcium arsenite suspension, and calcium chlorid to other lots. These were sprayed upon tomato, bean, and cucumber plants in comparison with calcium arsenite alone and calcium nitrate and calcium chlorid alone. In almost every instance the injury was increased slightly by the addition of the nitrate and chlorid, though these compounds in themselves caused no injury. After repeated tests we decided that other factors than the restraint of ionization must enter in. This question is now receiving further study.

TOBACCO EXTRACT

This insecticide has come into quite general use for the control of plant lice. It will often save the labor of one spraying application to combine it with an arsenical spray mixture. The results of such combination in injury to the foliage are shown in Table X. The conditions under which the tests there recorded were carried on as to dates, localities, arsenical chemicals, etc., are essentially as described on page 521. The tobacco extract is the "Black Leaf 40." It was used at the rate of 2.5 cc. to each 2 liters of water.

It is evident from Table X that the effect of tobacco extract upon the injurious properties of the arsenical compounds is not marked. It is probable that we may safely state that it does not increase the injury with any of the arsenicals tested, to such an extent as to make its use undesirable and on the other hand it does not decrease the injury in any case enough to make this an important consideration.

TABLE X.—*Effects of tobacco extract on the burning properties of various arsenical compounds*

Arsenical compounds to which tobacco extract was added.	Number of brands.	Number of applications.	Number of times injury increased.	Number of times injury decreased.	Number of times injury was the same.	Number of times there was no injury with or without the extract.
Arsenic trioxids	2	2	0	0	1	1
Arsenic disulphid	1	1	1	0	0	0
Arsenic trisulphids	2	4	0	1	1	2
Barium arsenate	1	2	2	0	0	0
Calcium arsenites	3	22	3	7	9	3
Copper aceto arsenites	2	20	2	6	4	8
Ferrous arsenates	3	15	1	0	1	13
Lead arsenates, triplumbic	7	62	3	2	0	57
Lead arsenates, diplumbic	13	97	5	3	2	87
Lead arsenates, mixtures	10	28	2	0	0	26
Zinc arsenites	6	52	8	3	10	31

SOAP

In spraying some plants, for example, cabbage, and to a less extent sugar beet, the spray mixture does not spread on the surface of the leaf and adhere, but rolls off in droplets, leaving most of the surface unprotected. It has been found that the addition of soap will nearly or quite obviate this. Furthermore, Parker (*22*) has shown that soap will very materially retard the settling of lead arsenate from its suspension in water. The natural tendency of soap to increase the solubility of the slightly soluble arsenical compounds is well recognized and the question arises, will this result in an increased tendency to injure the foliage on the part of some or all of the arsenical insecticides?

During this investigation several different kinds of soap were tried and several strengths were used, but in the tests recorded in Tables XI and XII one brand [11] was used exclusively, 14.4 gm. being added to each 2 liters of spray mixture. The arsenical chemicals were the same in kind and strength as recorded on page 521.

TABLE XI.—*Effects of soap on the burning properties of various "insoluble" arsenical compounds*

Arsenical compounds to which soap was added.	Number of brands.	Number of applications.	Number of times injury increased.	Number of times injury decreased.	Number of times injury was the same.	Number of times there was no injury with or without the soap.
Arsenic trioxids	4	105	16	7	11	71
Arsenic disulphids	1	14	2	0	0	12
Arsenic trisulphids	2	17	9	1	3	4
Barium arsenates	1	9	4	1	4	0
Calcium arsenates	1	77	48	6	17	6
Calcium arsenites	3	123	27	28	63	5
Copper aceto arsenites	2	123	8	64	28	23
Ferrous arsenates	3	29	1	0	0	28
Lead arsenates, triplumbic	8	95	13	1	0	81
Lead arsenates, diplumbic	13	140	56	0	1	83
Lead arsenates, mixtures	10	57	19	0	0	38
Lead arsenite	1	5	4	0	0	1
Zinc arsenites	6	90	11	10	17	52

Table XI shows that of the "insoluble" arsenicals tested all but three cause greater injury if soap is added. This increased injury is most conspicuous in the lead arsenates. Of these, 8 brands were triplumbic, 13 diplumbic, and 10 were probably mixtures of both. The increase of injury through the addition of soap is a little more pronounced with the diplumbic than with the triplumbic arsenates, but the difference is not so great as some have supposed.

One of the most surprising observations made in this phase of the investigation is the reduction in injury caused by copper aceto-arsenite when soap is added.

Not all brands of soap give the same results when combined with arsenical spray mixtures. Some appear to retard the injury by copper aceto-arsenite more than others, and they vary in the degree to which they increase the injury by lead arsenates and other compounds. Neither do they show equal power to keep lead arsenate in suspension. While

[11] "Diamond C."

considerable work was done with different soaps, 18 in number, the results were not sufficiently consistent and conclusive to warrant a detailed statement concerning them. It seems probable that the product of some of the soap factories is not uniform, and the number of brands on the market is great and the assortment found in different parts of the country varies so much that it seemed inadvisable to attempt to study them fully. However, it may at least be said that some quite consistently give bad results with the arsenicals and others are relatively harmless, while still others are variable. The brand most used in this investigation[12] was rather consistent and intermediate in its effect upon the arsenicals.

Soap appears to have some effect also upon the injurious properties of the soluble arsenical compounds, as shown in Table XII. This tendency is in general toward reduction when soap is added, but it is not so marked as to have great significance. Perhaps the more even spread on the leaf surface would account for it.

TABLE XII.—*Effects of soap on the burning properties of soluble arsenical compounds*

Soluble arsenical compounds to which soap was added.	Number of applications.	Number of times injury increased.	Number of times injury decreased.	Number of times injury was the same.	Number of times there was no injury with or without soap.
Arsenic acid	9	0	4	3	1
Ammonium arsenate	7	0	2	3	2
Cacodylic acid	3	0	0	3	0
Potassium arsenate	7	0	4	0	3
Potassium arsenite	8	1	3	4	0
Potassium cacodylate	5	2	1	1	1
Sodium arsenate	10	0	3	3	4
Sodium arsenite	9	1	2	4	2
Sodium cacodylate	5	0	1	2	2

LIME-SULPHUR AND TOBACCO EXTRACT

It may be at times desirable to add both lime sulphur and tobacco extract to lead arsenate or other arsenical spray mixtures, provided the efficiency of neither is destroyed and the resulting mixture is not dangerous to foliage.

TABLE XIII.—*Effects of lime sulphur and tobacco extract on the burning properties of various arsenical compounds*

Arsenical compounds to which lime sulphur and tobacco extract were added.	Number of brands.	Number of applications.	Number of times injury increased.	Number of times injury decreased.	Number of times injury was the same.	Number of times there was no injury with or without soap.
Arsenic trioxids	1	2	0	0	0	2
Calcium arsenites	1	10	0	7	2	1
Copper aceto-arsenite	1	16	7	1	4	4
Ferrous arsenites	1	2	1	0	0	1
Lead arsenates, triplumbic	4	38	19	0	0	19
Lead arsenates, diplumbic	9	58	25	1	0	32
Lead arsenates, mixture	6	12	12	0	0	0
Zinc arsenite	2	30	10	4	0	16

[12] "Diamond C."

A comparison of Tables IX and XIII leads to the conclusion that the addition of lime-sulphur and tobacco extract to arsenical spray mixtures has practically the same effect upon the foliage as lime sulphur alone.

Arsenic trisulphid may constitute an exception, but our tests with this compound combined with both tobacco extract and soap are too few to be conclusive. It is doubtful, however, if the trisulphid will ever come into general use as an insecticide.

LIME SULPHUR, TOBACCO EXTRACT, AND SOAP

This combination with arsenical compounds is not a desirable one as it often forms a curdled mass that is difficult to apply to the foliage. It also has a greater tendency to injure the foliage than any other combination we have tried. Calcium arsenite in combination with these three substances is the only exception, as may be seen by Table XIV.

TABLE XIV.—*Effects of lime-sulphur, tobacco extract, and soap upon the burning properties of various arsenical compounds*

Arsenical compounds to which lime-sulphur, tobacco extract, and soap were added.	Number of brands.	Number of applications.	Number of times injury increased.	Number of times injury decreased.	Number of times injury was the same.	Number of times there was no injury with or without soap.
Arsenic trioxids	2	5	3	1	0	1
Arsenic disulphid	1	2	2	0	0	0
Arsenic trisulphids	2	5	5	0	0	0
Barium arsenate	1	1	0	0	1	0
Calcium arsenites	3	17	2	8	4	3
Copper aceto-arsenites	2	20	12	2	3	3
Ferrous arsenates	3	8	2	1	0	5
Lead arsenates, triplumbic	8	51	29	0	0	22
Lead arsenates, diplumbic	13	84	57	0	0	27
Lead arsenates, mixtures	11	30	26	0	0	4
Zinc arsenites	6	40	17	1	1	21

GELATIN, AGAR, AND MILK

While soap is probably the best material known to make spray mixtures spread on leaves of cabbage, sugar beets, etc., where there is a tendency to roll off the smooth or waxy surface, its tendency to increase injury by most arsenical compounds gives an incentive to search for some other spreader. Moore (*21*) has given a very thorough discussion of the principles and practices of spreaders in spraying work, and a full bibliography of the subject. Gelatin, agar, and separated milk, having possibilities along this line, were tested in our work with various arsenical compounds to determine if they would influence the burning.

The gelatin was used in strengths of 0.1 per cent and 0.4 per cent (i. e., 1 and 4 grams to the liter). The agar was used in strengths of 0.01 and 0.04 per cent. The separated milk was used in strengths of 0.1 per cent and 0.4 per cent. Various arsenical spray mixtures, including lead arsenate, Paris green, and calcium arsenite, were tried singly and in combination with these three "spreaders" both on greenhouse plants and in the field, and also in the orchard. Repeated experiments showed no tendency on the part of these materials to increase the arsenical injury, and while they are not so efficient as soap in pro-

moting the adhesion of the mixture, yet they may be regarded as very serviceable. The agar in strengths used increased the spreading power least and would have to be used much stronger, perhaps 0.1 per cent, but gelatin 0.4 per cent and milk 0.4 per cent were quite satisfactory for sugar beets, though only moderately so for cabbage.

LIME

It has been recommended by Kilgore (*14*) that lime be added to Paris green and other arsenicals to restrain the injurious action on the foliage.

On tomatoes and beans in the greenhouse we have tested quite thoroughly unslaked lime with calcium arsenite and, with fewer repetitions, with lead arsenate (Corona) and with Paris green. Quite consistently the use of lime has very materially reduced the burning action of these three arsenical compounds as shown by Table XV.

TABLE XV.—*Effect of lime in combination with arsenical compounds*

Date.	Plant.	Chemical.	Amount in 2 liters.	Lime.	Injury.
			Gms.	*Gms.*	
July 25, 1917	Tomato	Calcium arsenite	1.9	None.	Bad.
Do	do	do	1.9	4.6	Do.
Do	do	do	3.9	None.	Defoliated.
Do	do	do	3.9	4.6	Partly defoliated.
Sept. 3, 1917	do	do	2.0	None.	Moderate.
Do	do	do	2.0	9.0	Slight.
Do	do	do	3.9	None.	Partly defoliated.
Do	do	do	3.9	9.0	Moderate.
Mar. 3, 1918	Bean	Lead arsenate (Corona).	9.7	None.	Very slight.
Do	do	do	9.7	9.7	None.
Do	do	do	19.5	None.	Moderate.
Do	do	do	19.5	19.5	None.
Do	Tomato	do	9.7	None.	Slight.
Do	do	do	9.7	9.7	None.
Do	do	do	19.5	None.	Moderate.
Do	do	do	19.5	19.5	None.
Sept. 3, 1917	do	Paris green	6.9	None.	Bad.
Do	do	do	6.9	6.9	Slight.
Do	do	do	9.2	None.	Very bad.
Do	do	do	9.2	9.0	Slight.

FERROUS SULPHID

Volck (*34*) especially has advocated the use of ferrous sulphid to decrease the burning effect of zinc arsenite. We have used this compound (7.2 gm. to 2 liters) many times in combination with different brands of calcium arsenite and of zinc arsenite and have found no general benefit in restraining the injury to the foliage. Usually the injury with and without the ferrous sulphid was the same, but occasionally it was a little more or a little less if the iron salt was added.

EFFECTS OF LETTING MIXTURES STAND BEFORE APPLYING

In the case of that group of arsenicals that are but slightly soluble in water and are often called "insoluble," one would naturally expect that if the suspension were applied as a spray as soon as mixed the amount

in solution would be less than if allowed to stand for some time and the injury correspondingly less. To what extent this principle will operate can be determined by experiment only.

To this end we have made repeated trials with arsenic trioxide and a few with calcium arsenite, calcium arsenate, lead arsenate, and Paris green.

Quite without exception the burning by arsenic trioxide steadily increased as the mixture was allowed to stand. Table XVI illustrates a typical demonstration of this fact. In this case suspensions of arsenic trioxide[13] (2.6 gm. in 2 liters) were prepared at different intervals so spaced that all would be ready for spraying at the same time, having stood the time periods indicated in the left hand column of the table. These suspensions after mixing were kept in an incubator at blood temperature and were stirred at intervals of about six hours, day and night. At the time of spraying the suspensions were thoroughly shaken and a small sample removed and filtered through Swedish filter paper, and the filtrate analyzed. The remainder was sprayed upon tomato and bean plants in triplicate.

TABLE XVI.—*Effects of letting arsenic trioxid stand after mixing*

Time after mixing.	Arsenic trioxid in solution.	Injury.	
		Bean.	Tomato.
	Per cent.		
5 minutes	0.001392	Slight	None.
1 hour	.002784	Moderate	Do.
2 hours	.006960	Very bad	Slight.
4 hours	.012520	Defoliated	Moderate.
8 hours	.016720	.....do	Do.
12 hours	.024128	.....do	Bad.
24 hours	.032480	Dead	Very bad.

Table XVI shows strikingly the progressive increase in burning by allowing arsenic trioxid to stand in suspension and the corresponding increase in the amount of the chemical that went into solution. Other experiments showed that this increase in injury as a result of standing continued for at least 48 hours and was strongly in evidence whether or not soap was added to the mixture. Kilgore (*14*) has shown that arsenic trioxid suspended in water continues to dissolve for 10 days.

The tendency of calcium arsenite, calcium arsenate, lead arsenate, and Paris green to increase in burning power as a result of standing in suspension is relatively slight.

EFFECTS OF REPEATED SPRAYING

It is often necessary for the control of insect pests to spray plants or trees two or more times at intervals of a few days or weeks, and in such cases it is important to know if the second or later applications are especially dangerous from the standpoint of injury to the foliage. Clinton and Britton (*2*) showed that the second application of zinc arsenite may do very serious damage, even though the first did little or no harm. Our work with two brands of zinc arsenite, Thomson's and "Ortho 40,"

[13] Baker's.

strongly confirms this observation. Quite uniformly the second application did much more damage than the first, and indeed a strength of 3.2 grams per liter, applied twice at intervals of about three weeks, did more harm than 6.4 grams applied once on either date. With calcium arsenite this tendency was noticeable but not nearly so pronounced as with zinc arsenite, while with lead arsenate and with copper acetoarsenite there was but little more injury after the second spray than after the first.

EFFECTS OF HUMIDITY

That humidity is one of the great contributing factors in arsenical spray injury is one of the most striking facts constantly in evidence throughout this investigation. This observation is by no means new and had already been noted by Gillette (*11*) and others; and certain manufacturers of lead arsenates have come to recognize the necessity of using safer mixtures on the Pacific coast and other humid regions than are required elsewhere.

Even with these facts in mind, however, we were almost astonished at the difference in results on leaves kept in moist and dry air. To demonstrate if possible the effects of humidity, an extensive series of spray mixtures was applied about simultaneously in different parts of the State, including an apple orchard near Flathead Lake (Mont.), where the humidity is generally relatively high. As it happened, however, this section was unusually dry during the course of the experiment and much more so than in the other localities where tests were made. Not a drop of rain fell for weeks and the dew point was not reached on a single night during the experiment. The days were rather hot, and wet and dry bulb thermometer readings made three times daily indicated a very low humidity every day and nearly every night. As a result almost none of the spray mixtures used caused any injury whatsoever. Even calcium arsenite (2 gm. in 2 liters of water) caused only slight injury. In the majority of cases, including all localities and dates, this compound in half this strength caused very serious injury to apple foliage, and sometimes defoliation.

A still more striking demonstration of the effects of humidity in extreme cases was made repeatedly by spraying tomato and other plants in pots and covering certain ones with bell jars and keeping duplicates outside. Under these conditions the moisture transpired by the leaves kept the air under the bell jars saturated.

The plants were all kept in diffused light in a basement laboratory to prevent rise of temperature under the bell jars as would happen if kept in direct sunshine. The plants were kept in this condition for usually one or two days and aerated twice daily. The bell jars were then removed and all plants placed under like conditions in the greenhouse until the notes were taken. Table XVII is representative of the results under these conditions.

Probably nothing in the whole series of experiments on arsenical spraying is more striking than the contrast of injury in dry air and in the saturated atmosphere under the bell jars, especially when soap is added. It might seem at first that the bell jar makes an extreme condition of humidity, but a saturated atmosphere out of doors is by no means unusual, especially near large bodies of water, as on the Pacific coast and in the Great Lakes region.

TABLE XVII.—*Showing the increased injury caused by a high humidity, procured by keeping sprayed tomato plants under bell jars*

Chemical.	Chemical in 2,000 cc.	Soap in 2,000 cc.	Injury.	
			Under bell jars.	Not under bell jars
	Gm.	*Gm.*		
Arsenic trioxid, Baker	1.3	None.	Slight	None.
Do	2.6	None.	do	Do.
Calcium arsenite, Baker	1.9	None.	Dead	Moderate.
Calcium arsenite, Adler	.6	None.	Very bad	None.
Do	.6	14.4	do	Do.
Lead arsenate, Baker, acid	9.3	None.	None	Do.
Do	9.3	28.8	Moderate	Do.
Lead arsenate, Baker, ortho	12.0	None.	None	Do.
Do	12.0	28.8	Moderate	Do.
Lead arsenate (Corona)	9.3	None.	None	Do.
Do	9.3	14.4	Very bad	Do.
Copper aceto-arsenite, Baker	2.4	None.	Nearly dead	Do.
Do	2.4	14.4	Very bad	Very slight.

To determine if it makes a difference whether the plants were placed in the saturated atmosphere immediately after spraying or after drying a short time, some were put under bell jars for the first three days and then removed while others were not covered at once but inclosed the fourth, fifth, and sixth days; and likewise some were kept under bell jars the first day only, others the second day only, and still others the third day only. Reducing the time, in another experiment some were covered the first hour after spraying, others the third hour, others the first hour of the second day and still others the first hour of the fifth day. The results showed that a saturated atmosphere for even so short a period as one hour considerably increased the injury, though a longer time caused still more damage. Considering the results in all these experiments it appeared to make little difference at what time after spraying the plants were covered, if not more than a few days, provided the time spent in this saturated atmosphere was the same.

It was noted that under the bell jars the plants were dripping with moisture; not only was the air saturated, but the surfaces of the plants were covered with films and drops of water. To learn if an increased amount of humidity is of significance when kept below the point of saturation, sets of tomato plants (three in a pot), were sprayed and dried, then one set was put under a tightly closed bell jar, one was put under a bell jar with the stopper removed and with a tiny crack underneath, and a third was left outside. All were kept in strong diffused light.

Under the jar with the stopper removed were placed wet and dry bulb thermometers and a tiny fan run by a toy motor. This was used to fan the wet bulb for one minute before reading the temperature.

The procedure was to spray 9 tomato plants, three sets of 3 in a pot, with the same mixture, let them dry for a few minutes, then inclose one set tightly under a bell jar 8 by 16 inches on a ground glass plate, inclose another set under a bell jar slightly open at the top and bottom as described above, and keep the third set on the table beside them without covering. After standing under these conditions for three days the plants were all carried to the adjoining greenhouse, where they were left uncovered for about 10 days, after which notes were taken.

Six such experiments were carried out, of which the one shown in Table XVIII is representative. In this case the plants were sprayed with calcium arsenite[14] (1.95 gm., in 2 liters of water; no soap added).

It will be seen that the humidity does not need to reach the saturation point (100 per cent relative humidity) to materially increase the injury over that in a drier atmosphere, although in the saturated atmosphere still greater injury was done. Presumably, other conditions being equal, the degree of injury will be in a certain relation to the relative humidity.

Wetting the leaves at frequent intervals after spraying did not, however, have the same effect as a humid atmosphere.

TABLE XVIII.—*Showing the increased injury caused by humidity produced by transpiration under bell jars*

Conditions.	Time.	Temperatures.			Degree of injury.
		Wet bulb.	Dry bulb.	Relative humidity.	
		F.	F.		
Under bell jar closed....	(a)	.....	.....	100	Plant dead.
Under bell jar partly closed.	8 a. m..	58°	62°	79	Partly defoliated.
	1 p. m..	64	66	90	
	5 p. m..	64	66	90	
	8 a. m..	60	62	89	
	1 p. m..	64	66	90	
	5 p. m..	64	66	90	
	8 a. m..	56	58	89	
	1 p. m..	58	60	89	
Not under bell jars.....	8 a. m..	57	64	65	Injury moderate.
	1 p. m..	60	68	63	
	5 p. m..	61	70	61	
	8 a. m..	56	64	60	
	1 p. m..	58	68	54	
	5 p. m..	59	67	62	
	8 a. m..	53	69	32	
	1 p. m..	55	61	68	

[a] Throughout.

Both in the greenhouse and out of doors sprayed foliage was given a light application of water through a fine spray nozzle every few hours throughout the day. The surrounding air was hot and dry and the leaves dried off very soon after each application. Under these conditions, if no soap had been mixed with the arsenical, the injury was not in any case noticeably greater than on the control plants that were sprayed with the same arsenical but not sprayed with water afterwards. In case soap had been added there was a slight tendency to increase the injury by subsequent sprayings with water, but this injury was incomparably less than produced by a humid atmosphere.

EFFECTS OF SOIL MOISTURE

As plants and trees can not always receive a sufficient amount of moisture through the roots it is but natural in spraying operations where foliage burning is liable to occur to raise the question as to whether or not a wilted condition of the leaves would affect the extent of injury.

[14] Baker's.

Greenhouse conditions have been found best for determining the answer, and we have made innumerable trials on tomatoes, beans, and other plants. When slightly or moderately wilted plants were sprayed in comparison with turgid ones, the resulting injury has been invariably practically the same. Any differences that have been noted were within the experimental error. The only cases in which there was a marked difference was when the wilting was so extreme and so long continued that the leaves were practically dying.

EFFECTS OF TEMPERATURE

A factor that might be supposed to affect arsenical injury is the temperature of the leaves and the surrounding air. In an effort to determine the effect of temperature upon the extent of injury to plants sprayed with arsenicals several series were run in a differential thermostat. This consisted of a series of chambers in which were maintained temperatures varying from 5° to 40° C. Light was admitted through glass at the top. Sprayed tomato and cucumber plants were placed in this thermostat for two days and then transferred to an open bench in the greenhouse.

The arsenicals used were diplumbic lead arsenate and Paris green.[15] It was found that between 5° and 15° C. there was little difference in the injury. From 15° to 25° the injury materially increased. Above 25° there was apparently a marked increase in the injury, but the unsprayed controls could not be kept in a healthy condition at these temperatures. Hence the records on the arsenical injury to sprayed plants at corresponding temperatures were of doubtful value.

These experiments show that an elevation of temperature increases the injury, but we wish to emphasize that under field and orchard conditions temperature is of minor importance as compared with humidity.

EFFECTS OF WOUNDING

In connection with studies made on the effects of arsenical compounds on the bark of fruit trees, we have shown (*29*, *30*) that the all-important factor in determining whether or not injury will occur is the integrity of the outer corky layers of the bark, i. e., whether or not this has natural or artificial openings. Are wounds important in determining the extent of injury through the foliage? We have often noticed that there is an excessive injury at the margins of the wounds made by hail stones, whipping by the wind, and other mechanical agencies. In some instances we have purposely made such wounds before spraying. In some of these cases the injury was strictly confined to the margins of such wounds, but this was only where the arsenical treatment was mild. In some instances where the injury was confined to a few scattered spots there was evidence of a tiny puncture in each spot, revealed only by the aid of a lens. Wherever the arsenical treatment was so severe as to injure the foliage badly, there was every evidence of absorption directly through the unbroken epidermis. The injury at the margins of wounds is strictly local, usually making a brown strip about one-eighth of an inch wide and, except where such wounds were unusually extensive, this injury is of little practical importance.

[15] Both Baker's.

EFFECTS OF SHAKING BRANCHES AFTER SPRAYING

Both in the practical orchard and field spraying and in experimental work there is often more or less wind that shakes some of the liquid from the leaves. It is important to know, therefore, the extent to which this will decrease the amount of arsenical injury to the foliage. In all the experimental work of this investigation the spraying was done when there was little or no wind, but this was probably an unnecessary precaution. On several occasions apple limbs were sprayed in duplicate, one being shaken vigorously immediately afterwards and the other hanging quietly until the spray mixture had dried on. Similar experiments were conducted with potted plants in the greenhouse. In no case was there a marked reduction in the amount of burning and usually no difference could be detected. As this shaking removed the excess liquid from the leaves so much more quickly and thoroughly than an ordinary wind, it is fair to conclude that any wind not strong enough to practically prevent spraying operations will have no material effect on the amount of arsenical injury.

EFFECTS OF LIGHT AND DARKNESS

Three experiments were conducted to determine if light increases or decreases the amount of injury caused by arsenical spraying.

Potted tomato plants were placed in a dark room in the evening. Early the next morning two were sprayed with calcium arsenite and put under bell jars in dark boxes wrapped with black cloth; two were sprayed and put under bell jars not in dark boxes, and unsprayed controls were kept under both these conditions. All boxes and bell jars were kept in a strong diffused light for two days and then the plants were removed and placed on a bench in the greenhouse. In two of the experiments the injury to the sprayed plants was equally bad in the dark boxes and in the light. In the third, all the sprayed plants were killed, making comparisons impossible. The unsprayed plants remained in healthy condition.

SIGNIFICANCE OF THE RESULTS

The place of arsenical compounds in the category of insecticides is so important that we can not at present expect their replacement by any other group of chemicals. They have their faults, however, and among these is the marked tendency to injury of the crop they are intended to protect. It is therefore of prime importance to learn the factors that determine this injury and with this knowledge to reduce it to a minimum. Some of the existing beliefs regarding this injury are founded on fact, the difficulty being to know the extent of the tendency. Other beliefs appear to the based on a wrong conception.

It has been found quite difficult to make exact statements concerning the toxicity of the different arsenicals because of the variability of their composition. This is especially true of the lead arsenates. Theoretically one might expect ortho, meta and pyro arsenates each in the form of monoplumbic, diplumbic, and triplumbic salts, a total of 9 possibilities. Actually the number that form is fewer, but, on the other hand, many commercial lead arsenates are not single salts of lead and an arsenic acid but a mixture of different lead arsenates. Furthermore, the product of a company may change from time to time, and even within a short

period different lots from the same factory may vary. It is encouraging that the product of certain companies is becoming stabilized, and it is to be hoped that others will follow their example. At the present time, however, we can not make definite statements about lead arsenate without specifying the brand and lot. These remarks apply in some degree to zinc arsenite and calcium arsenite, while Paris green and arsenic trioxid are much more uniform in composition.

It is rather surprising that calcium arsenate should ever have been used as extensively as it was some 20 years ago when one observes its tendency to burn foliage. To be sure, the competition with other arsenicals, e. g., lead arsenate, did not then exist, and in the less frequent injury by these compounds we find one of the chief causes of its progressive abandonment.

The most striking example of a poorly founded prejudice is the quite general belief that arsenic trioxid (common white arsenic) will burn foliage even when occurring as a very small impurity in other arsenicals. We are not able to explain fully this belief. Probably it lies partly in the fact that chemists expressed their findings of soluble arsenic in insecticides in terms of "arsenious acid," the reasons for which are not always clear to others. Probably also, the letting of the spray mixture stand for hours or days before applying increases the danger from arsenic trioxid more than from other arsenical compounds, and has been a factor. In any event, we feel that we have established quite conclusively that a freshly prepared suspension of arsenic trioxid is not particularly harmful to foliage, and we entertain a hope that this relatively cheap form of arsenic may come into general use for the control of certain insects. Of course its efficacy as an insecticide has yet to be determined.

The hope expressed by Gillette (*11*) that arsenic trisulphid would prove less injurious than the arsenical insecticides in common use, seems unlikely of realization, for, while this compound has a low solubility in pure water, it nevertheless causes considerable burning when sprayed upon foliage.

In the selection of an arsenical insecticide for any crop to be sprayed, the entomologist will do well to consult the table of susceptibility on page 512, for on some plants a mixture may be used that would be quite destructive to others.

The practice of adding to an arsenical spray mixture some other material to act as a supplementary insecticide or fungicide, or as a "sticker" or "spreader," or to decrease the tendency to injury, has been the subject of considerable controversy. Conspicuous among these materials is soap, which, in addition to being a spreader, has been shown by Parker (*22*) to be of considerable value in keeping lead arsenate in suspension. That soap increases the tendency to burning by nearly all "insoluble" arsenicals is clearly established (p. 523), but it is safe to say that the increase in burning tendency with lead arsenate is not sufficient to discourage its use on the more resistant plants such as cabbage, sugar beets, potatoes, and apple. It is indeed a fortunate circumstance that cabbage and sugar beets, on which a spreader is a necessity, are resistant enough to arsenical injury to make the use of soap permissible. It is likewise fortunate that soap has been found to actually decrease the injurious properties of Paris green, for gardeners may now rest assured that the addition of soap to it is not only permissible but desirable. Lime sulphur increases the injury by nearly all the arsenical insecticides in about the same degree that soap does, and must not be used in com-

bination with them on very tender foliage. The fact that lime sulphur decreases the injury caused by calcium arsenite appears to be of only scientific interest, for even with this addition the burning will be so severe that this arsenical is not useable under most circumstances. Tobacco extract gives no increase in the injury by any of the arsenicals.

Of the environmental conditions, only humidity seems to be of large significance, for while the burning is increased in a measure by a rise in temperature, it is doubtful if this tendency is great enough within the range of temperatures encountered in the field to be entitled to practical consideration. The effect of humidity, however, can hardly be overrated and must be given large consideration in all spraying operations. To be sure, this factor is not under the control of the orchardist and farmer, but he can make a fair estimate of the humidity that is likely to prevail following spraying in his locality, and be bold or cautious in the selection of his spraying material.

The varying results observed in this investigation when spraying experiments were repeated under conditions identical, except as to weather, show the significance of atmospheric conditions, but, what is of especial importance to the investigator, these varying results show the great danger in drawing conclusions from single experiments.

SUMMARY

Based on an investigation extending through a period of 10 years, and involving the application of various arsenical spray mixtures to approximately 10,000 separate plants and branches of trees sprayed individually, we submit the following conclusions concerning arsenical injury to foliage:

(1) The name commonly used does not indicate the composition of an arsenical with sufficient exactness. This is especially true of the calcium arsenites, lead arsenates, and zinc arsenites, in which the results obtained by using different lots labeled the same except as to manufacturer may give widely divergent results. The arsenic trioxids and Paris greens are much more uniform in composition.

(2) The arsenical insecticides least injurious to foliage are iron arsenate and certain of the lead arsenates. Possibly new ones will be proposed that will be as safe or safer.

(3) Of the lead arsenates not all pure diplumbic ortho-lead arsenates are identical in burning properties, nor are all triplumbic ortho-lead arsenates identical in this respect. Some diplumbic lead arsenates are as safe to use as some of the triplumbic ones.

(4) Arsenic trioxid is not so dangerous to the foliage as is generally supposed, and indeed this compound is permissible as an insecticide on any but the most delicate foliage, provided it is applied promptly after mixing with water.

(5) Standing after mixing causes a very marked increase in injury by arsenic trioxid and a slight increase in injury by other arsenical insecticides.

(6) Of the readily soluble arsenical compounds cacodylic acid and sodium and potassium cacodylates proved the most injurious. This is quite in contrast to the well recognized fact that these compounds of arsenic are less harmful to the higher animals than most others.

(7) The foliage is more susceptible to arsenical injury than the fruit or the stems.

(8) The injury to leaves is characterized, first, by a lack of luster, then wilting, and a final change to some shade of brown (dependent upon the species of plant) as the affected tissue becomes dead and brittle. The symptoms are not sufficiently distinctive to separate arsenical injury from some others.

(9) The injury to the foliage is practically all through the lower epidermis, regardless of the numbers of stomata in the two surfaces, indicating that it is a result of direct penetration of the thinner cuticle.

(10) Individual plants of the same species and variety vary somewhat in their susceptibility to arsenical injury.

(11) The older leaves of a plant are more susceptible than the younger ones.

(12) Soap added to soluble arsenicals offers a slight protective action.

(13) Soap added to most insoluble arsenicals increases the injury by increasing the solubility to a point more than counteracting its slight protective action.

(14) Soap added to Paris green in suspension distinctly restrains the burning of foliage.

(15) Gelatin, milk, and agar do not increase the arsenical injury to foliage.

(16) Lime sulphur increases the injury caused by most insoluble arsenical compounds.

(17) Lime sulphur distinctly decreases the injury caused by calcium arsenite but not to a sufficient extent to make this a safe insecticide.

(18) Tobacco extract has little influence upon the injurious properties of arsenical insecticides.

(19) Lime restrains, to some extent, the injury by calcium arsenite and Paris green.

(20) We have not been able to decrease the zinc arsenite injury by adding ferrous sulphid.

(21) Repeated spraying with zinc arsenite is liable to result in serious burning.

(22) A slightly wilted condition of the foliage does not result in increased injury.

(23) Light seems not to be an important factor in arsenical injury to foliage.

(24) An increase in atmospheric temperature results in a moderate increase in arsenical injury; but within the ranges of temperature found during the summer in a suitable orchard climate this is of little practical importance if the air is relatively dry.

(25) Humidity is the greatest environmental factor in determining arsenical injury to foliage, and this influence is very marked even before the saturation point is reached.

(26) Using a few experiments as a basis for generalization upon arsenical injury is a treacherous proceeding and may lead to erroneous conclusions. The only safe procedure is to test repeatedly each point under consideration.

LITERATURE CITED

(1) BOURCART, E.
1913. INSECTICIDES, FUNGICIDES, AND WEEDKILLERS. xxxv, 431 p., illus. London.

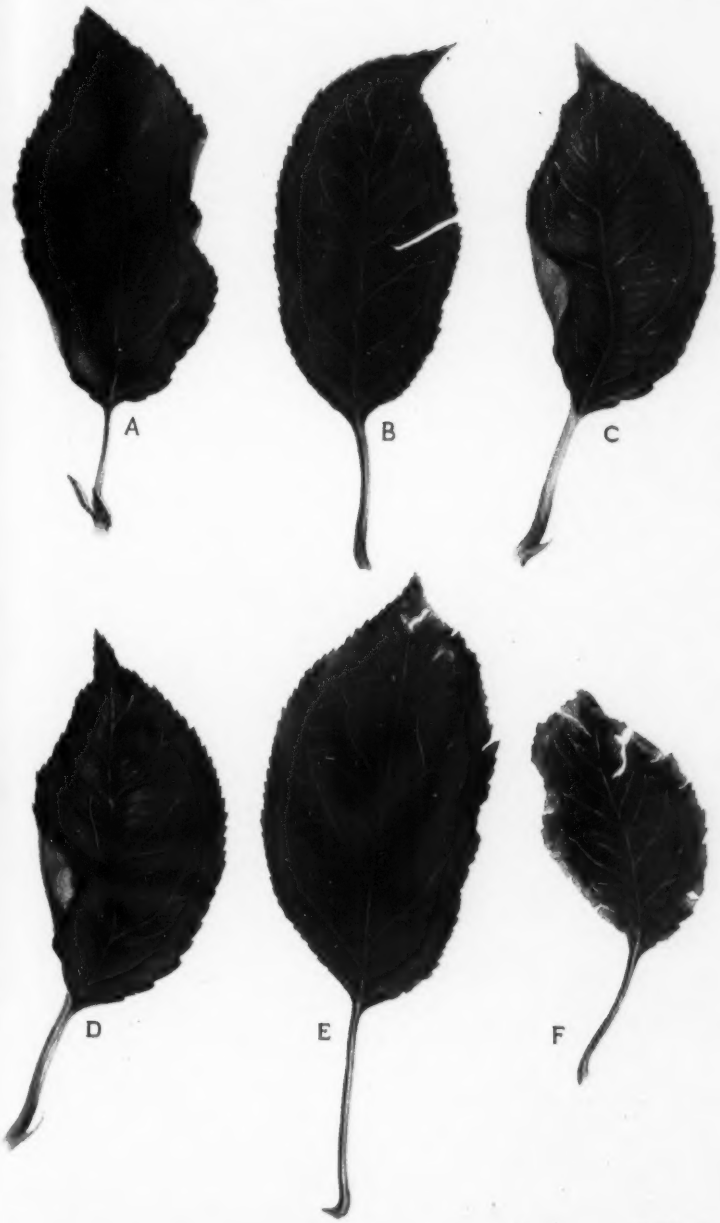
(2) CLINTON, G. P., and BRITTON, W. E.
1912. TESTS OF SUMMER SPRAYS ON APPLES, PEACHES, ETC. *In* Conn. Agr. Exp. Sta. 35th Ann. Rpt. 1911, p. 347–406, pl. 17–24.

(3) COOLEY, R. A.
1912. ORTHO ARSENITE OF ZINC AS AN INSECTICIDE. *In* Jour. Econ. Ent., v. 5, p. 142–146, pl. 2.
(4) CORDLEY, A. B.
1909. LIME-SULPHUR SPRAY PREVENTIVE OF APPLE SCAB. *In* Better Fruit, v. 3, no. 10, p. 33–35, illus.
(5) ———
1910. THE LIME-SULPHUR-ARSENATE OF LEAD MIXTURE. *In* Better Fruit, v. 4, no. 11, p. 37–41, illus.
(6) CUSHNY, Arthur R.
1910. A TEXTBOOK OF PHARMACOLOGY AND THERAPEUTICS. Ed. 5. 744 p., 61 fig. Philadelphia. Bibliographies interspersed.
(7) EDGERTON, J., and THOMAS, C.
1861. POTATO INSECTS. *In* Prairie Farmer, v. 8, p. 115.
(8) FERNALD, C. H.
1894. INSECTICIDES. THE HORN FLY. Mass. (Hatch) Agr. Exp. Sta. Bul. 24, 15 p., 2 fig.
(9) ———
1898. ARSENATE OF LEAD AS AN INSECTICIDE. *In* 45th Ann. Rpt. Mass. State Bd. Agr., 1897, p. 353–356.
(10) GILLETTE, C. P.
1888. ARSENIC EXPERIMENTS. *In* Iowa Agr. Exp. Sta. Bul. 2, p. 30–35.
(11) ———
1890. EXPERIMENTS WITH ARSENITES. *In* Iowa Agr. Exp. Sta. Bul. 10, p. 401–420.
(12) HAYWOOD, J. K., and MCDONNELL, C. C.
1910. LEAD ARSENATE. U. S. Dept. Agr. Bur. Chem. Bul. 131, 50 p., 1 fig., 4 pl.
(13) JOHNSTON, Fred A.
1912. ARSENITE OF ZINC AND LEAD CHROMATE AS REMEDIES AGAINST THE COLORADO POTATO BEETLE. *In* U. S. Dept. Agr. Bur. Ent. Bul. 109, p. 53–56.
(14) KILGORE, B. W.
1891. ON THE CAUSE AND PREVENTION OF THE INJURY TO FOLIAGE BY ARSENITES TOGETHER WITH A NEW AND CHEAP ARSENITE, AND EXPERIMENTS ON COMBINING ARSENITES WITH SOME FUNGICIDES. N. C. Agr. Exp. Sta. Bul. 77b (Tech. Bul. 2), 11 p.
(15) LEBARON, William.
1872. SECOND ANNUAL REPORT ON THE NOXIOUS INSECTS OF THE STATE OF ILLINOIS. p. 97–166, illus.
(16) LODEMAN, E. G.
1910. THE SPRAYING OF PLANTS. xvii, 399 p., 92 fig. New York.
(17) LUTHER, E. E.
1911. SPRAYING TREES WITH ZINC ARSENATE OF LEAD. *In* Better Fruit, v. 5, no. 8, p. 65–66.
(18) MELANDER, A. L.
1910. MIXING ARSENATE OF LEAD AND SULPHUR LIME. *In* Better Fruit, v. 4 no. 9, p. 47, illus.
(19) ———
1912. THE CONTROL OF THE CODLING MOTH. *In* Better Fruit, v. 6, no. 12, p. 11–13, 7 fig.
(20) MERCK and Co.
1907. MERCK'S 1907 INDEX. Ed. 3. xiii, 472 p. New York.
(21) MOORE, William.
1921. SPREADING AND ADHERENCE OF ARSENICAL SPRAYS. Minn. Agr. Exp. Sta. Tech. Bul. 2, 50 p., illus. Literature cited, p. 46–50.
(22) PARKER, J. R.
1911. THE USE OF SOAP TO RETARD THE SETTLING OF CERTAIN ARSENICALS. Mont. Agr. Exp. Sta. Bul. 86, p. 37–45.
(23) PFEFFER, W.
1900. THE PHYSIOLOGY OF PLANTS. Ed. 2. 3 v., illus. Oxford.
(24) SCHOENE, W. J.
1913. ZINC ARSENITE AS AN INSECTICIDE. N. Y. Agr. Exp. Sta. Tech. Bul. 28, 16 p.
(25) SCOTT, E. W. and SIEGLER, E. H.
1915. MISCELLANEOUS INSECTICIDE INVESTIGATIONS. U. S. Dept. Agr. Bul. 278, 47 p.

(26) SMITH, John B.
1896. ECONOMIC ENTOMOLOGY. xii, 481 p., 483 fig. Philadelphia.
(27) ———
1903. INSECTICIDES AND THEIR USE. N. J. Agr. Exp. Sta. Bul. 169, 27 p.
(28) ———
1908. ARSENATE OF IRON. *In* N. J. Agr. Exp. Sta. 28th Ann. Rpt. [1906]/07, p. 475–476.
(29) SWINGLE, D. B., and MORRIS, H. E.
1911. A PRELIMINARY REPORT ON THE EFFECTS OF ARSENICAL COMPOUNDS UPON APPLE TREES. *In* Phytopathology, v. 1, p. 79–93, pl. 16–17.
(30) ———
1917. ARSENICAL INJURY THROUGH THE BARK OF FRUIT TREES. *In* Jour. Agr. Research, v. 8, p. 283–318, pl. 79–84. Literature cited, p. 317–318.
(31) TAYLOR, E. P.
1910. SCIENCE'S WARFARE ON FRUIT TREE PESTS. *In* Nat. Hort., v. 1, no. 5, p. 3–5, 15, 18, illus.
(32) VERMOREL, V., and DANTONY, E.
1909. DE L'EMPLOI DE L'ARSÉNIATE FERREUX CONTRE LES INSECTES PARASITES DES PLANTES. *In* Compt. Rend. Acad. Sci. [Paris], tome 148, p. 302–304.
(33) VOLCK, W. H.
1910. FOLIAGE TESTING OF ARSENICALS. 4 p. Watsonville, Calif.
(34) ———
1913. CATERPILLARS, CODLING MOTH, APHIDS. *In* Better Fruit, v. 7, no. 7, p. 16–18, illus.
(35) WOODWORTH, C. W.
1890. THE EFFECTS OF THE ARSENITES UPON PLANTS. Ark. Agr. Exp. Sta. Bul. 14, 14 p.
(36) ———
1911. HISTORY OF SPRAYING IN THE PAJARO VALLEY. *In* Better Fruit, v. 5, no. 10, p. 65–70.
(37) ——— and COLBY, George E.
1899. PARIS GREEN FOR THE CODLING-MOTH. Calif. Agr. Exp. Sta. Bul. 126, 40 p., illus.

PLATE I

Stages in the development of arsenical spray injury on apple foliage.
A.—Three days after spraying.
B.—Four days after spraying.
C.—Five days after spraying.
D.—Seven days after spraying.
E.—Ten days after spraying.
F.—Twenty-five days after spraying.


A
B
C
D
E
F